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Industrial Engineering in Hospitals

by **HAROLD E. SMALLEY**

Professor of Industrial Engineering, Georgia Institute of Technology

FOR the past few years, Industrial Engineers in increasing numbers have been concerning themselves with engineering and management problems in industries other than manufacturing. Industrial Engineering principles and practices have been adopted to varying degrees in the processing industries, the service industries, public utilities, governmental activities, commercial pursuits, office work, agriculture, and even homemaking. There appears to be a growing realization that competitive, profit-motivated manufacturers have no exclusive need for scientific management and that practical adaptations of it, in whole or in part, can help non-manufacturing industry achieve a higher quality-cost ratio.

Viewed properly, there is no inconsistency between *Industrial* Engineering and (*non-manufacturing*) *industry*. The dictionary defines industry as "skill, cleverness, ingenuity, use of skill or craft, habitual diligence in any employment or pursuit, steady attention to business, human exertion employed for the creation of value." The term is not limited to manufacturing. It includes all aspects of instrumentalities relating to intrinsic satisfactions. Thus, *industry* is considered to be man's effort to maximize value satisfactions. In this context, Industrial Engineering is the use of engineering principles and practices to facilitate the creation of value satisfactions and includes the analysis, synthesis, and control of all productive elements of all industry.

HOSPITAL APPLICABILITY

One of the industries which has interested an increasing number of Industrial Engineers since World War II is the health services industry (3) (7) (10). Measured in terms of capital outlay, number of employees, or dollar volume, this economic institution is among the largest in the economy. Expenditures for medical and hospital services rose from three billion dollars in 1940 to more than twelve billion dollars in 1956 (15). Advances in health technologies, an ever-increasing demand for more and better services, expanding population, higher costs of living, and an adverse demand and supply relationship in the labor market are among the factors which have forced hospital and medical costs upward (2). Hospitals, government, management, labor unions, and the general public appear to be genuinely concerned about the momentous problems of financing the cost of health care. It is not surprising that some of the leaders in each of these groups look to Industrial Engineering as one of the means by which quality-cost problems can be solved.

There appear to be three schools of thought with respect to Industrial Engineering for hospitals. One holds to the belief that little can be done about monetary costs but holds that Industrial Engineering might help point the way toward lower non-monetary costs. This school would look to Industrial Engineering for ways and means of reducing energy, effort, inconvenience, obnoxiousness, anxiety, fear, and other negative values. It would welcome but would not expect reductions in labor, material, and overhead costs; it would anticipate better morale and job satisfaction, improved public relations, wiser utilization of available personnel and resources, and higher levels of quality. A second school includes those who believe that Industrial Engineering has no place whatever in the health field. This group opposes all that is suggestive of production-line efficiency and rebels at proposals to adopt conservation measures similar to those used in manufacturing. A third school is just as dogmatic in advocating transplantation of manufacturing techniques into hospitals. This group looks to Industrial Engineering as a virtual panacea for the problems of hospital administration.

The most logical and constructive assumption with regard to Industrial Engineering applicability would seem to be a modification of the first school of thought. This modification would retain the objectives of lower non-monetary costs and better morale, public relations, and quality, but also it would include more optimism concerning monetary savings and more emphasis upon Industrial Engineering as a tool of hospital management. Such a doctrine would seem to be consistent with the true nature of Industrial Engineering as well as with the conditions believed by some to be peculiar to hospitals.

THE METHODS IMPROVEMENT MOVEMENT

The history of a formal methods improvement movement in hospitals can be traced back no further than the present decade, although informal, unorganized efforts probably parallel the entire history of hospitals. Frank B. Gilbreth, just after the turn of the century, was probably

the first Industrial Engineer to use motion study techniques in hospitals.[1] His wife and professional partner, Lillian M. Gilbreth, has given considerable impetus to the application of Industrial Engineering in the health field. In 1945, writing in a hospital journal, she stated that:

> It would now seem time for the hospital group itself to take over the entire project of the utilization of available material in this field, to evaluate what has been done, to estimate what needs to be done and to utilize to the full the cooperation that is available from all of us who are working in the time and motion study field (4).

In response to the interest in methods improvement which was beginning to be shown by member hospitals, the American Hospital Association created a committee to study this relatively new field. Col. F. H. Gibbs, former chairman of this committee, has related the Association's objectives, as follows:

> Realizing the increasing importance of better ways of providing hospital care through improved methods, the American Hospital Association set up a committee in 1952 to search out ways in which the Association might better serve hospital management in the phase of scientific management known as "Organized Methods Improvement" (14).

Most of the programs undertaken since 1951 have been studies of case problems and short courses in work simplification, although a few instances of research, education, and professional practice have been reported (9).

Health leaders seem to be undecided as to what facets of Industrial Engineering are appropriate for the hospital, how the applicable facets can be properly integrated into the hospital setting, and by what means implementation can be achieved. These instances of indecision comprise a challenge to the Industrial Engineering profession, for only through professionalism can we avoid a repetition in this field of the unfortunate practices of the despised "efficiency expert" in the manufacturing field. Ill-advised programs at this critical time can set the methods improvement movement back for decades to come. Professional Industrial Engineers cannot let this happen.

As indicated above, a few professionals have entered the hospital field. Gottleib (6) evaluated prosthetic devices by use of motion and time study, and Schoeller (8) wrote several articles on the use of the work simplification approach in hospitals. Several Industrial Enigneers have been employed by hospitals as full-time staff specialists, and at least four medical centers have professional engineering service available on a substantial basis.[2] Management and engineering societies have become interested in assisting hospitals as a civic duty and a number of helpful projects have resulted (1) (5). Nevertheless, the mainstream of hospital methods improvement is flowing along lines of the traditional do-it-yourself approach. Dangerously, professionalism is but an eddy in the rising tide of in-service training of hospital people on a non-professional basis.

The enthusiasm for Industrial Engineering in health institutions has varied somewhat from one health profession to another. Nurses have pioneered the advocacy of Industrial Engineering for hospitals, although doctors, dentists, pharmacists, and others are beginning to display some interest in this field as results become apparent. Applications to the practice of medicine not only have come slowly but have come largely from laymen or from doctors in administrative positions. The emphasis has been upon the doctor's participation in changes in the methods of others, not upon the methods and procedures of doctors themselves. Dentistry and pharmacy play relatively minor roles in hospital management; comparatively little attention has been given these areas of application. There probably are marked differences in attitudes of administrators, ranging from a determination to economize to an indifference to costs.

Certain departments or areas within the hospital lend themselves more readily to Industrial Engineering work than others. In departments like laundry and maintenance, being far removed from the site of patient bed care, techniques virtually can be *transplanted* from manufacturing. However, as one gets nearer the bedside, he might have to *adapt* techniques to fit different criteria for success.

The various tools and techniques of Industrial Engineering have been applied to varying extents in the hospital. Methods determination and methods correction were the first segment to be applied; also methods work has had the most extensive applications. As attempts to adapt Industrial Engineering to the health field mature, additional tools undoubtedly will be tried and tested.

THE PROBLEM OF SEMANTICS

Misunderstanding is undoubtedly a factor in the attitudes of health leaders toward Industrial Engineering. There is a continuum of attitude along which opinion varies from one of advocating rapid and wide-spread adoption of virtually all techniques of Industrial Engineering to one of advocating opposition to the introduction of any new program. Logic probably will dictate some middle course, but logic is not likely to prevail in an atmosphere of misunderstanding. The professional engineer is in the best position to make constructive contributions in this realm. If and when the problem of semantics is settled, attention then can be focused on organized methods improvement for hospitals on its merits.

---

[1] This work is demonstrated in the film production, "The Original Films of Frank B. Gilbreth," edited by James S. Perkins and produced by the Chicago Chapter of the Society for Advancement of Management, 1944.

[2] Emory University, State University of Iowa, Johns Hopkins University, and the University of Pittsburgh.

TRADITIONALISM

Traditions can be both a blessing and a handicap. They help to promote unity and give substance to an identity, to a sense of belonging. They tend to foster an *esprit de corps* and the system of teamwork. Traditions also intensify habit and custom and support the *status quo*. Psychological inertia often thwarts progress by resistance to change. Historical factors tend to perpetuate the bad as well as the good. There can be little question that these factors compound the Industrial Engineer's difficulties and challenges and that historically-rooted characteristics of hospitals create problems that stand in the way of effective application of Industrial Engineering principles to hospitals.

UNIQUENESS

The health industry differs from manufacturing, processing, and commercial industries in many ways, yet there are many similarities. The modern hospital is an industry specializing in certain complex services. It is called upon to provide these services day and night, seven days a week. The hospital is subject to most of the economic fluctuations—secular, seasonal, and cyclical—which characterize business activity. It is keyed to the economic status of the community and to the psychological and sociological attitudes of the people it serves. The hospital, like other business, must compete for land, labor, capital, and managerial ability and is susceptible to the dislocations of technological change. Prices which the hospital may charge are subject to the test of social acceptability in the long run, but profit-motivated business must pass this same test in both the long and short runs.

The hospital, being a service industry, manufactures no product, yet a large general hospital does considerable processing and fabricating in its dietary department, laundry, central sterile supply, and other departments. Services are diversified and largely non-standardized. There are no assembly lines, yet the typical hospital has many routine, repetitive procedures which have characteristics more nearly like the production line than many jobbing-type manufacturing plants.

It has become conventional for some hospital people to claim *uniqueness* on the grounds that in even the departments far removed from the patient, hospitals cannot practice mass production as manufacturers can. This claim is not well founded since most manufacturing and almost all non-manufacturing in our many industries are *not* done on a mass production basis. It is safe to say that American industry, popular notions to the contrary notwithstanding, is characterized by the small, diversified, jobbing concern, a rather appropriate description of a typical hospital.

In the hospital the Industrial Engineer faces two kinds of problems in relation to the matter of uniqueness, those stemming from *real* differences and those stemming from *imagined* differences. It is important to realize, however, that both kinds are real problems for the Industrial Engineer since they both manifest themselves in terms of *resistance to change*. The most enlightened and constructive attitude for health leaders would seem to be one in which similarities, not differences, between hospitals and other organizations are stressed. It behooves the professional Industrial Engineer to employ a *modus operandi* consisting of a liberal dose of initiative, salesmanship, diplomacy, tact, and patience in order to combat irrational claims that "we are different." Given such attitudes and methods of operation, Industrial Engineering principles and practices can be adapted to the hospital to facilitate attainment of hospital objectives at minimal cost.

INDOCTRINATION

As indicated, differences of opinion have been advanced in recent years concerning the application of efficiency programs for hospitals, and it is likely that controversy will continue for some time to come. However, there is one aspect of the methods improvement movement which enjoys almost unanimous support. That is the need for a climate of attitudes characterizing sympathy for methods improvement, as a prerequisite for organized methods improvement.

Enlightened management in all industries has recognized for some time that programs affecting or depending upon people must be explained to these people in an effort to obtain their support. Techniques for achieving this all-important first step vary widely, but almost everyone agrees that without it the best intended program is doomed to failure. Indoctrination in some of the simpler tools and techniques of Industrial Engineering has been found to be a powerful means of attaining these goals through *education*.

The problem of establishing a suitable attitude climate takes on the dimensions of *direction*, *location*, and *magnitude* of indoctrination. The proper direction of indoctrination is from the top down, while the location is in hospital administration, nursing service, and department heads. The magnitude of indoctrination will vary. The board of trustees should have a "faith" level, while department heads and, perhaps, medical staff will need "appreciation." The "understanding" level is required by the administrative officer who is responsible for the program, and practitioners must be "technically competent." The total program should be directed by an Industrial Engineer who is "professionally competent."

The establishment of a suitable climate for Industrial Engineering practice and the inauguration of an Industrial Engineering program are entirely different matters. The former is a prerequisite to, not a substitute for, the latter. There is no reason to believe that hospital people generally appreciate this apparent truism. It is

important, however, that both the hospital and the engineer distinguish between *indoctrination* and *implementation*. Indoctrination deals with the rudiments or elementary principles of Industrial Engineering, while implementation relates to the accomplishment, completion, or fulfillment of the major purposes of Industrial Engineering.

IMPLEMENTATION

The forces which motivate hospitals to embark upon an organized methods improvement program probably vary in magnitude and direction. Some hospitals appear to be content with conventional hospital management methods, while others feel obliged to strive continually for improvement. In relatively recent years, a number of hospitals have instituted some form of a work simplification program and a few have what is purported to be a formalized, permanent program. Very few institutions have full-fledged Industrial Engineering programs.[3] It is entirely possible that some hospitals engage in economy programs of one sort or another because they feel a sense of responsibility in managing the community's resources for restoring health and that others give lip service to efficiency because it seems fashionable to do so. In any event the movement is rather slow and is along traditional lines of do-it-yourself.

Having decided upon a program of implementation, the hospital can then turn to the question of which approach to implementation is to be used. There appear to be numerous approaches which might be used. These can be classified as *intermittent* and *continuous*. Among the intermittent are consultative, university affiliation, community service, hospital association, and commercial interests. The continuous category includes in-service programs and professional programs.

Before one can determine which approach to implementation is best he must establish criteria against which to judge characteristics of the several approaches. It would appear that three main criteria can be used here. These are *continuity, compatibility,* and *competence.*[4]

Space does not permit a full discussion of the attributes of these approaches to implementation, but we can make certain generalizations based upon inherent characteristics. Only the in-service and professional approaches provide continuity; these two plus the hospital association approach have compatibility; while the consultative, university affiliation, community service, and professional approaches embody competence. These characteristics of the several approaches may be summarized, as follows:

Approach	*Continuity*	*Compatibility*	*Competence*
Consultative	No	No	Yes
University Affiliation	No	No	Yes
Community Service	No	No	Yes
Commercial Interests	No	No	No
Hospital Association	No	Yes	No
In-Service	Yes	Yes	No
Professional	Yes	Yes	Yes

If the criteria employed can be accepted and if the comparisons made are adjudged logical, the general conclusion can be drawn that the professional approach to implementation is best.

Having decided upon the professional approach, the hospital is faced with the practical problem of structuring the program. Implementation of a policy of organized methods improvement by the professional approach requires a professional program. Unfortunately, very few hospitals have had experiences with such a program. Most of these are limited in scope since most embrace merely methods engineering and virtually all are still experimental, being less than five years old. Thus, very little is actually known about the elements of a successful program. More time is needed in which to gain experience and more experimentation is needed in order to determine effects of program characteristics upon success. In addition, there is need for legitimate research in the problem areas identified through experience. Of course, we can draw upon what is known about hospital programs generally and upon the extensive experiences of other industries with scientific management programs.

Another problem associated with the professional approach is the question of supplying the hospital's demand for professional engineers. In 1957, there were some 6,966 hospitals in this country with a total of 1,607,692 beds and 1,374,704 full-time employees (12). Assuming a need for one engineer for every 150 beds (9), American hospitals will have to compete with manufacturing and other industries for 10,718 vacancies! It is estimated that 2,795 engineers would be needed if hospitals of 100 beds or more obtained the services of only one engineer each. A recent survey reveals an average of 13.9 Industrial Engineers per 1,000 employees in manufacturing plants (13). Using this index, hospitals could use 19,108 Industrial Engineers. Ignoring engineer turnover and hospital growth in our dynamic health industry, it is probably safe to predict that our current supply of some 1,590 Industrial Engineering graduates annually will not satisfy the demand in hospital and non-hospital industry (11). A partial solution to this problem may be found in more active participation by hospitals in the engineering market and

[3] In a survey made in 1956 and 1957, it was found that only about twelve percent of the hospitals in a geographical area where methods improvement had been stressed had any kind of an organized program. Nationally, the percentage can be expected to be lower. This same survey uncovered but nine Industrial Engineers across the country who devoted most of their time to hospital problems. Three of these are known to have left the hospital field.

[4] "Cost" might be included as a fourth criterion, but this is a continuous variable dependent upon other factors.

in the use of professionally supervised technicians. The long-range solution probably lies in a conscious attempt by the industrial segment of our economy, including hospitals, to encourage and foster the development of a larger and better reservoir of scientists and engineers and to make the best possible use of the talent it does have.

CONCLUSIONS

A sound organized methods improvement program for hospitals will be dependent upon:

1. The establishment of a receptive atmosphere within the hospital organization.
2. The soundness of the initial installation of methods and controls.
3. The conduct of a continuing program of in-service education and professional implementation.

The hospital personnel will need leadership, guidance, and inspiration; some will need sympathetic understanding of their problem areas; all should get honest evaluation of *bona fide* suggestions; and many will need technical assistance in converting embryonic proposals into practical terms. It should be realized that, although a major portion of those properly approached will be sympathetic to the Industrial Engineering program, not all personnel will have a keen desire for innovation. Even the conscientious and well-informed are often shackled by bias, tradition, and subjectiveness.

If professionalism is to prevail in hospital practice, Industrial Engineers must take a more active part in education, research, and practice. Educational activities should include short courses for health-oriented people, training courses for sub-professional methods technicians, talks at hospital conventions and institutes, and articles in hospital journals. Research activities might include studies of case problems, development of ways in which Industrial Engineering tools can be adapted to the hospital, and investigations to determine the practical effects of the hospital environment on professional practice. More Industrial Engineers should become interested in offering professional services to hospitals as consultants and as employees on a staff specialist basis.

A permanent Industrial Engineering program will be a substantial effort toward the attainment of major objectives in the hospital and it will be the best insurance against uncontrolled costs. Such an organized methods improvement program can secure the best possible patient care at the lowest cost to the hospital, to the patient, and to the community.

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Order Sizes for Job Lot Manufacturing

by **R. W. LLEWELLYN**

Associate Professor of Industrial Engineering, North Carolina State College

THE correct order quantity for the job lot order is a subject that has had little formal study. The subject is of interest in many cases, the following being some examples:

1. A company receives a firm order for a specified quantity of a custom-designed product, there being no other customer for any excess that might be produced in the production run.
2. A company orders parts from one of its own departments to make a modification to a standard product for a special customer. The company will have no use for any excess parts produced.
3. A foundry produces parts which are placed in an annealing oven for heat treating. If a quantity larger than the capacity of the oven is produced in the preceding pouring operation, the excess must be scrapped because of damage caused by quick cooling.

Many other examples could be cited, but these are sufficient to show that the situation exists in many forms. The problem of determining the quantity to start in such instances results from the fact that there is shrinkage in any manufacturing operations due to process losses. This shrinkage may be of two types. The first is a systematic loss of one or two pieces per operation due to set-up activities. Pieces are deliberately spoiled in making a set-up or the first one or two pieces (or gallons of a liquid, etc.) are discarded at the start of a run for various reasons. This type of loss is constant and can be easily measured. It can be offset by a simple addition to the start quantity as otherwise determined. The second type of loss is that resulting from random causes, the resulting loss being likewise random.

Consider a situation in which the average proportion defective $\bar{p}$ in a process is known from previous production runs. (In instances of true job lot work, reasonable estimates may be made from past work of a similar nature). We know that the proportion defective will not be $\bar{p}$ on each run because of the fact that the losses have been assumed to come at random. Rather, the loss will average $\bar{p}$ but are likely to be above or below $\bar{p}$ in a particular run. If the quantity to start is determined by simply allowing for this proportion defective it would insure sufficient production only about one-half of the time. Stated another way, the probability of having at least enough of the product to fill the order would be only .5.

Let us now suppose that we wish to increase the probability of having n good pieces at the end of the run to .95 where n is the customer order size. Let us further suppose that the product np is greater than or equal to 5 so that the binomial distribution is satisfactorily approximated by the normal distribution. The standard deviation for the binomial distribution is:

$$\sigma = \frac{\bar{p}(1 - \bar{p})}{n} . \qquad \text{Eq. 1.}$$

This standard deviation may be assumed to be the standard deviation of the normal distribution as well. Now, we wish at least n products at the conclusion of the production run. This means that there should not be more than some critical percent defective p' in the lot such that when the defectives are subtracted from some start quantity n', slightly larger than n, there will be at least n left. The critical percent defective is established by the confidence level desired. At the 95% confidence level, for example, the percentage defective p' that will be exceeded only 5% of the time is located 1.645 σ above the mean $\bar{p}$. Note that the entire critical range is located above the mean. There is no percent defective below the mean that will endanger our yield of *at least* n units of the product. Having located p' we can proceed to calculate n' by:

$$n' = \frac{n}{1 - p'} \qquad \text{Eq. 2.}$$

As an example of this type of calculation, take the following: A manufacturer receives an order for 900 units of a product. The average per unit defective on the class of work is 5%. If at least 900 are not produced, an additional order must be placed on the shop. How many should be started to insure a yield of at least 900?

$$\sigma = \frac{p(1 - p)}{n} = \frac{.05(.95)}{900} = .00005278 = .00737$$

$$p' = \bar{p} + 1.645$$

and $p' = \bar{p} + 1.645(.0073) = .0620.$

Therefore, the quantity to start is

$$n' = \frac{n}{1 - p'} = \frac{900}{1 - .0620} = \frac{900}{.9380}$$

$$= 959.48 \text{ or } 960 \text{ units.}$$

This answer is in a sense an approximation, since the original standard deviation was calculated for $n = 900$. Repeating the calculations, we get:

$$\sigma = \frac{.0475}{960} = .00703$$

$$p' = .05 + 1.645(.00703) = .0616$$

$$n' = \frac{900}{1 - .0616} = \frac{900}{.9384} = 959 \text{ units.}$$

The second answer is close enough. In many instances the second approximation will differ from the first more than it does in this instance. In very few cases will it be necessary to make a third approximation.

To illustrate the opposite type of problem, consider a case in which we wished to be sure that not more than a certain number of the product were finished. The case of limited annealing oven capacity is an example. Suppose the oven capacity is 900 units and we wish to be sure, at the 95% confidence level, that not more than 900 units are produced in the operation preceding the annealing. The analysis proceeds as before except that now we have to place the critical range below the mean. This means that p' is now 1.645 below $\bar{p}$.

Using the same data as before:

$$\sigma = .00727 \text{ (in the first approximation)}$$

$$p' = \bar{p} - 1.6456 = .05 - 1.645(.0073) = .038$$

$$n' = \frac{900}{1 - .038} = \frac{900}{.962} = 935.6 \text{ or } 936 \text{ units.}$$

A second approximation to this answer could be obtained as before.

To consider a third variation of this method assume that 900 units are to be started in an operation and packing material must be ordered for it. What is the amount of packing material we should order so as to be sure that we have enough at the 95% level of confidence? Here again we are concerned with too few defectives, so we have the critical range again below $\bar{p}$, giving up a p' of .038 as in the second example. Since the number being started 900 is known, the calculation of n' (cartons to order) comes from the equation:

$$n' = n(1 - p') \text{ or}$$
$$n' = 900(.962) = 865.8 \text{ or } 866 \text{ cartons.} \qquad \text{Eq. 3.}$$

Finally, the last case of interest here might be illustrated by a case in which boxes were being made up in a packing room. Here we might want to prevent, at the 95% level of confidence, preparing too many in advance. So here the critical interval would be above $\bar{p}$, p' would be .062, as in the first example, and n' becomes 844.2 or 844 cartons.

These illustrate the four main variations of problems that can be worked in this manner. It should be obvious that these can be calculated at any desired level of confidence.

POISSON DISTRIBUTION

In the event the proportion defective is small, the normal distribution is not a good approximation to the binomial distribution. For $n\bar{p}$ less than 5, the Poisson distribution can be used to answer some of the same type of problems. This can best be illustrated by an example.

Suppose the problem is like the first encountered except that $\bar{p}$ is .005 instead of .05 ($n\bar{p}$ now equals 4.5 instead of 45.0). We wish to hold the number good, at the end of the process, to at least 900. This type of problem is best worked by use of Tables such as those in Grant (1). This table is a tabulation of the cumulative probabilities of this distribution for various values of $n\bar{p}$. Four lines of this table are reproduced in Table 1.

The table is interpreted as follows. The probability of no defectives in the lot when $n\bar{p} = 4.4$ is .012. The probability of 1 or 0 defectives (not more than 1) is .066. The probability of 6 or fewer defectives is .844, etc. To locate a point corresponding to the 95% confidence interval of the normal distribution, we must find the point where the cumulative probability is .95 of x or fewer defectives. Interpolating in the table for $n\bar{p} = 4.5$, we get a cumulative probability of .913 for $x = 7$ and .960 for $x = 8$. Since the Poisson distribution is discreet, the allowance must be for either 7 or 8 defectives, 8 being chosen here because it strengthens the confidence level rather than weakens it. To carry the calculation to a second approximation, $n\bar{p}$ is recalculated:

$$n\bar{p} = 908 \times .005 = 4.54$$

TABLE 1

*Cumulative Poisson Distribution**

								x							
np	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
4.4	.012	.066	.185	.359	.551	.720	.844	.921	.964	.985	.994	.998	.999	1.000	
4.6	.010	.056	.163	.326	.513	.686	.818	.905	.955	.980	.992	.997	.999	1.000	
4.8	.008	.048	.143	.294	.476	.651	.791	.887	.944	.975	.990	.995	.999	1.000	
5.0	.007	.040	.125	.265	.440	.616	.762	.867	.932	.968	.986	.995	.998	.999	1.000

* Reprinted by permission from *Statistical Quality Control*, by E. L. Grant, McGraw-Hill Book Company, Inc., New York, 1952, 2nd edition, Appendix, Table G.

By interpolating between 4.4 and 4.6, we find that the cumulative probabilities are .910 and .958 for $x = 7$ and 8 respectively. This means that 8 extra should be run as before. No further approximations are necessary.

The corresponding calculations for the three other variations of the problem, corresponding to the three other variations worked with the normal approximation are straightforward. If we wish to make not more than a certain quantity, we search for a cumulative probability equal to or below $1 - \alpha$ where α is the significance level involved.

ECONOMIC CONSIDERATIONS

The foregoing analysis is adequate in these cases in which management desires protection at a given confidence level that there will not be too much or too little production loss for a given situation. In some instances, however, it may be desirable to try to find a mode of operation which will permit minimizing the cost of protecting against an unusual percent defective. For example, in the case of the pure job lot order, it may be possible to rush a second lot through the plant before the shipping date if production losses are excessive on the first run. Here management would wish to avoid starting too many pieces, some of which would always have to be scrapped even though of satisfactory quality, or of taking too large a risk of running a second lot with its attendant set-up expenses.

Let us denote the unit cost of the product, at the end of the process, by U and set-up costs by S. α will be used to signify the significance level being used and E the number of pieces above the desired lot quantity which are started because of the lack of perfect quality. Using the notation employed earlier:

$$E = n' - n.$$

Now, the extra pieces that must be started through the process are irrevocably committed and constitute an expense regardless of the actual percent defective resulting from the run. In $1 - \alpha$ proportion of runs, E extra pieces will be adequate. In α proportion of the runs, a second lot must be processed. In all cases, the cost of the desired n good pieces must be incurred and the set-up costs of the first lot can not be avoided. The cost of protecting against bad quality in the good runs is UE, the cost of the E pieces committed to this use. In the case of a poor run, the cost of the second set-up is also incurred. Thus the total costs of potential high losses on the run are, on the average:

$$C = UE(1 - \alpha) + (UE + S)\alpha = UE + S\alpha \qquad \text{Eq. 4.}$$

It is true that in the case of a second run, some more pieces must be made, which will cost money, and there is a possibility of a third run being necessary. For the moment, these factors will be regarded as negligible.

In the example used earlier with the Poisson distribution, $n = 900$, $\bar{p} = .005$ and $\alpha = 5\%$. It was concluded that 8 parts had to be started over the desired 900. If $U = \$2.00$ per piece and $S = \$100.00$, the protection cost is (using the true $\alpha = .042$ from the Poisson distribution for $x = 8$ at $n\bar{p} = 4.54$):

$$C = 2 \times 8 + 100\ (.042) = \$20.20.$$

There is a one-to-one correspondence between E and α in Eq. 4. That is, assuming one determines the other. Since E can take on only integral values, it is simplest to select values of E and determine the corresponding values of C and α.

Taking $E = 7$, for which $\alpha = .09$,

$$C = 2 \times 7 + 100\ (.09) = \$23.00.$$

In Table 2 are calculated values of C and α for various values of E from 5 to 12. From either, the most economical value of E is seen to be 9 units and the corresponding significance level to be 1.8%. In Table 3, the effect of variable unit cost is shown by calculating the cost as a function of E when U equals \$1 per unit and \$5 per unit and S remains fixed. It is seen that the effect is to require more extra units (equivalent to operating at a higher confidence level) when the ratio of unit cost to set-up cost is low. When the ratio is high, it is economical to reduce the safety factor. These results are intuitively logical.

TABLE 2

Calculation of Costs of Protecting against Uncertainty of Product Quality and Corresponding Significance Level for $U = \$2.00$/piece and $S = \$100.00$

E	UE	α	$S\alpha$	C
5	10	.304	30.40	40.40
6	12	.174	17.40	29.40
7	14	.090	9.00	23.00
8	16	.042	4.20	20.20
9	18	.018	1.80	19.80
10	20	.007	.70	20.70
11	22	.003	.30	22.30
12	24	.001	.10	24.10

TABLE 3

Continuation of Calculations of Table 2 for $U = \$1.00$/piece and $U = \$5.00$/piece

E	$U = \$1.00$/piece		$U = \$5.00$/piece	
	UE	C	UE	C
5	5	35.4	25	55.4
6	6	23.4	30	47.4
7	7	16.0	35	*44.0*
8	8	12.2	40	44.2
9	9	10.8	45	46.8
10	10	*10.7**	50	50.7
11	11	11.3	55	55.3
12	12	12.1	60	60.1

* Italicized entries are column minimums.

EFFECT OF SECOND ORDER PROBABILITIES

In the development of Eq. 4. mention was made of the

fact that it might be necessary to make a third and subsequent set-up and that in the second run some quantity of the product must be made, all of which is chargeable to higher production losses than were anticipated at the given level of confidence. Thus the possible costs in the α proportion of cases when the losses are excessive are $S + Un'' (1 - \alpha_1) + (Un'' + S)\alpha_1$ where n'' is the total quantity needed in the second lot and α_1 is the level of risk taken that the second lot will be adequate to fill the order. We will assume a condition where the risk factor will be the same in each lot so that $\alpha_1 = \alpha$. Then we may replace the given second lot cost in Eq. 4. by the expression above as follows:

$$C' = UE + S\alpha + [Un'' (1 - \alpha) + (Un'' + S)\alpha]\alpha \quad \text{Eq. 5.}$$

$$C' = UE + S\alpha + Un''\alpha + S\alpha^2 \quad \text{Eq. 6.}$$

In general, one cannot calculate from Eq. 6. because it is impossible to predict how poor the lot quality will be in those cases in which the percent defective exceeds the critical value. Let us assume, however, that in a particular run p in the first lot is .02. This is a definite shift from the assumed .005 and results in 18 defective pieces, more than any E of Table 2. Now we must make an additional run to make up the deficit which will include enough to cover any defective units in the second lot.

Even though the percent defective was 2% rather than .5% in the first lot, we will assume that in a new set-up the usual $\bar{p} = .005$ can be achieved, on the average. Using the true binomial method of computing probabilities, the probability of a defective if 13 are started, in the case where E in the first lot was 5, is much less than .304. Therefore, maintaining α at the same value as in the first run, no extra pieces over the 13 needed should be started in this second run. In the case where the first E was 6, 12 must be ordered and again no extra pieces are needed. At the point where the first E was 8 and 10 additional pieces are needed, however, it is necessary to start one additional piece to maintain the confidence level equal to that established in the first run. For all original E's from 8 through 12, one extra piece started will permit the α of the second run to be no larger than the α of the first run.

Utilizing Eq. 6. and values of n'' as determined, calculations may be performed to obtain the results shown in Table 4. A comparison of Table 4 on one hand with Tables 2 and 3 on the other shows that in two of the cases the inclusion of second order probabilities does not change the value of E for which the cost is a minimum. In the calculations for $U = \$5$ per piece, the optimum number of extra pieces to start in the first run is shifted from 7 to 8. This example leads to the conclusion that the second order probabilities are negligible in this type of problem. As indicated earlier, they cannot be considered in practice, so the result is fortunate. Since second order probabilities are unimportant, we can proceed by induction and conclude that third and higher order probabilities may likewise be neglected.

TABLE 4

Calculation of Costs of Protecting Against Uncertainty of Product Quality When Second Order Probabilities are Included

E	n''	$C'(U=1)$	$C'(U=2)$	$C'(U=5)$
5	13	\$48.59	\$57.54	\$84.40
6	12	28.52	36.61	60.87
7	11	17.80	25.79	49.76
8	11	12.84	21.30	*46.69*
9	10	11.04	*20.22*	47.36
10	9	*10.76**	20.83	51.02
11	8	11.32	22.35	55.42
12	7	12.01	24.01	60.04

* Italicized entries are column minimums.

METHOD OF COMPUTATION

It is possible to determine directly the correct number to start to minimize the cost of protecting against uncertainty of process quality. Eq. 4. gives this cost as a function of E and α. U and S are considered fixed for a given situation. For some E, say E_0, and a corresponding α, say α_0, this cost is a minimum. At $E_0 - 1$ and $E_0 + 1$, the cost must be larger, so:

$$U(E_0 - 1) + S\alpha_{0-1} > UE_0 + S\alpha_0 < U(E_0 + 1) + S\alpha_{0+1}, \text{ where } \alpha_{0-1} \quad \text{Eq. 7.}$$

corresponds to $E_0 - 1$ and α_{0+1} to $E_0 + 1$.

Working with the right two members of Eq. 7.

$$E_0 + \frac{S}{U}\alpha_0 < E_0 + 1 + \frac{S}{U}\alpha_{0+1}$$

$$E_0 < E_0 + 1 + \frac{S}{U}(\alpha_{0+1} - \alpha_0)$$

$$0 < 1 + \frac{S}{U}(\alpha_{0+1} - \alpha_0) \text{ and, finally,}$$

$$\alpha_0 - \alpha_{0+1} < \frac{U}{S} \quad \text{Eq. 8.}$$

Now, $\alpha_0 = \sum_{x=E_0+1}^{n} \frac{n\bar{p}^x e^{-n\bar{p}}}{x!}$ and

$$\alpha_{0+1} = \sum_{x=E_0+2}^{n} \frac{n\bar{p}e^{-n\bar{p}}}{x!}$$

so that $\alpha_0 - \alpha_{0+1}$ equals the $E_0 + 1$ term of the Poisson distribution which has a mean and variance of $n\bar{p}$. To demonstrate this, in the problem for which the solution is given in Table 2, we have:

$$\alpha_0 - \alpha_{0+1} < \frac{U}{S} = \frac{2}{100} = .02$$

In Molina's Tables (2) the first term for which the probability is less than .02 is 10, which identifies $E_0 + 1$. E_0 is then equal to 9, in agreement with the result of

Table 2. For $U = 1$, $E_o = 10$ and for $U = 5$, $E_o = 7$, in agreement with Table 3.[1]

In the type of situation in which $n\bar{p} > 5$, where the normal approximation to the binomial is usually used, the method still gives useful results. For example, in the problem worked in the early part of this paper, $n = 900$ and $\bar{p} = .05$. If we assume $U = 2$ and $S = 100$, then the method of Eq. 8. can be used but with $n\bar{p} = .05 \times 960$ (approximately) $= 48.0$. From Molina's tables $E_o = 57$, the actual cost at $E = 57$ is

$$C = UE + Sz = 57 \times 2 + 100 \ (.0870) = \$122.70$$

Calculations show that the true minimum, using the normal distribution instead of the Poisson as the approximation to the binomial, is at $E_o = 56$, a difference of only 1 piece. As the calculations are much easier by the Poisson method and the true $\bar{p}$ is usually not known to a high degree of accuracy, the Poisson method is to be preferred. For repetitive use by clerks, a tabulation of the correct E_o for various n, $\bar{p}$, U and S could be made that would simplify use of the method.

[1] Grant constructed his tables from Molina's but summed his probabilities from o to x instead of from x to ∞, making them more suitable for problems like the one in the second part of this paper. For the present problem, the individual terms are needed, which Molina provides.

SUMMARY

This article has shown how it is possible to calculate the correct number to start in a job lot case in order to hold to within a given confidence level of producing the required number of pieces. A formula was derived for determining the most economical number to start in situations where non-economic considerations did not predominate. Finally, a simple procedure for calculating the optimum start size of the order was given which can be used for wide ranges of the mean of the Poisson distribution.

REFERENCES

(1) Grant, E. L., *Statistical Quality Control*, 2nd ed., McGraw-Hill Book Company, Inc., New York, 1952.

(2) Molina, E. C., *Poisson's Exponential Binomial Limit*, Van Nostrand, New York, 1942.

A Method for Measuring Physiological Cost of Work[1]

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ANY attempt by American Industrial Engineers to compare work methods on the basis of physiological cost has been plagued by the shortcomings of available apparatus. Until recently it was necessary to have the subject breathe into large bags which not only encumbered his movements but also seriously limited the length of time for the task. The analysis of the gas by the traditional methods was a time consuming process requiring considerable skill. This is no longer true as there are now available better instruments which are accurate and simple to operate, so that the Industrial Engineer should now take a fresh look at metabolic measurements as a means of measuring work. The Industrial Engineer should realize that he has new and more sensitive tools to push farther into the study of how man can work more effectively.

The techniques to be discussed here were developed by work-physiologists and anyone interested in using these techniques is strongly advised to read a number of publications on this type of research. It is also an advantage to discuss the methodology with those who have had extensive experience in this area of research.

This method, it should be remembered, is for measuring

[1] This study forms part of the Purdue Farm Cardiac Project, AES Project No. 712, leader Dr. L. S. Hardin, sponsored by Indiana Heart Foundation and American Heart Association. Authorized for publication as Purdue University Agricultural Experiment Station paper #1207.

The authors acknowledge the assistance given in this study by J. B. Liljedahl, Agriculture Engineering Department, Purdue University.

[2] This material is extracted from the Ph.D. dissertation of the senior author which was presented in partial fulfillment of the requirements of the Department of Industrial and Management Engineering, State University of Iowa, Chairman, Professor J. Wayne Deegan.

physiological costs as reflected by caloric values. It does not reflect, except perhaps in an indirect way, the psychological cost incurred in doing work.

THE METABOLIC METHOD

Muller and Heising of the Max Planck Institute of Work Physiology describe three methods of determining the energy expenditure in man (14). Only one method is of interest here but to appreciate this method, the other techniques will be described briefly.

The first method described involves a dietary study including an exact statement of the caloric intake. Such a technique would be far too difficult for common use. In any case, the method cannot be used for individual tasks, but only for the total daily activity.

The second method is that of conventional calorimetry in which the mechanical and heat energy is measured. This again is far too complex and can only be performed in specially equipped laboratories.

The third method, and the one recommended here, depends upon the oxidation of nutritive materials—fat, carbohydrates, and protein—so that the oxygen consumed during work is an indirect measure of the energy expenditure for the work. In this method, the volume and composition of the expired air has to be determined.

By this last method as originally conceived, the expired air was collected in a rubberized bag; subsequently the volume and composition of the expired air was determined. As can be seen the estimation of caloric expenditure by this method essentially involves two steps, measurement of the volume of gas exhaled and the measurement of the gas composition.

DETERMINING THE QUANTITY OF AIR

It is no longer necessary to have the worker breathe into large bulky bags as has been done in the past, for it is now possible to pass the gas directly through a lightweight gasometer designed for this purpose by the Max Planck Institute of Work Physiology, Dortmund, Germany.

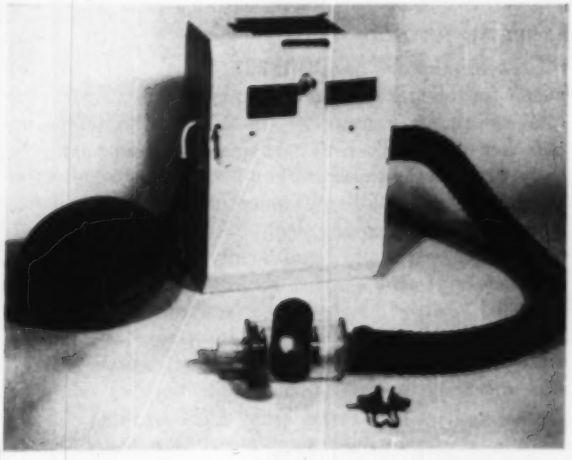

Fig. 1

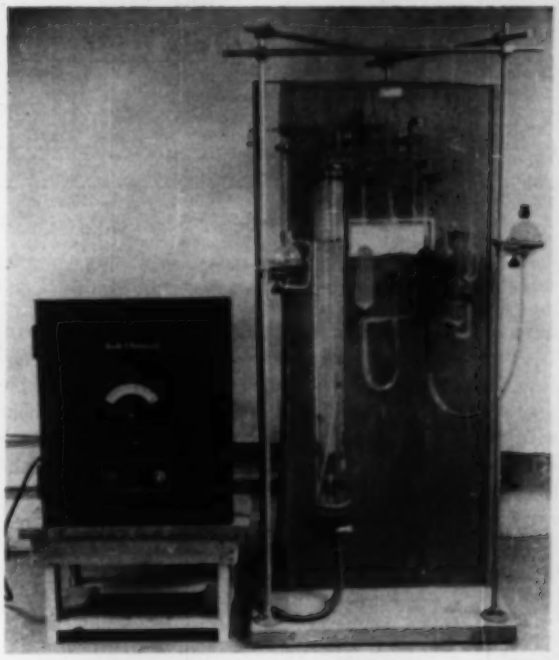

Fig. 2

This gasometer, shown in Figure 1, has been improved over the years. It consists of two chambers separated by a wall of leather in such a way that as one chamber empties the other one fills. Movement of the leather diaphragm is transferred to a crankshaft which drives a counter indicating the volume of air passing through the meter. This crankshaft also drives a pump which samples a small percentage of the expired air and delivers it to a small rubber bag for subsequent analysis. The counter which registers the volume in cubic meters can be disengaged at will and at the same time the sampling device is disconnected. The gas temperature, used to compute the volume at standard temperature, is indicated by a thermometer within the expired air stream.

The gasometer is connected to the subject by a flexible pleated hose fitted with a valve and mouthpiece or a face mask. The respiration valve is constructed of light plastic parts and is fitted with two small rubber or plastic valves so that inspired air can flow through the valve body and into the mouth, and the expired air must pass out through the rubber hose to the gasometer. The subject has a rubber mouthpiece in his mouth and breathes through it.

Since it is essential that all of the expired air flows through the gasometer, it is necessary for the subject to wear a small nose clip. If the subject has ruptured ear drums, precautions should be taken against any possible loss of expired air through the ears.

MEASUREMENT OF OXYGEN CONCENTRATION

Until quite recently the Haldane analyzer was the

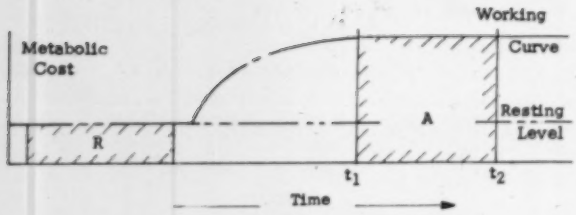

FIG. 3. Steady State Method

common instrument for determining the oxygen and carbon dioxide concentration in the exhaled air. This technique requires a skilled analyst and takes considerable time for the analysis of each sample. Such an instrument with its elaborate and fragile glassware is shown on the right hand side of Figure 2, and at the left is the Beckman-Pauling Oxygen Analyzer with which analysis can be made very rapidly.

The principle upon which the Beckman instrument operates is that oxygen is strongly paramagnetic (attracted into a magnetic field) while other gases, with few exceptions, are slightly diamagnetic. In effect the Beckman analyzer measures the magnetic susceptibility of the gas sample which is primarily due to oxygen. Within the gas chamber of the instrument is a nitrogen filled dumb-bell-shaped test-body mounted on a quartz fiber. This test body is suspended in a strong nonhomogeneous magnetic field and as the oxygen content of the sample gas-chamber changes, the test body rotates until the magnetic force on the test body is balanced by the torsional restoring force of the quartz fiber. The amount of torsion is sensed by a photomultiplier tube transforming a change in oxygen concentration into a voltage difference. The instrument is calibrated by means of standard gases.

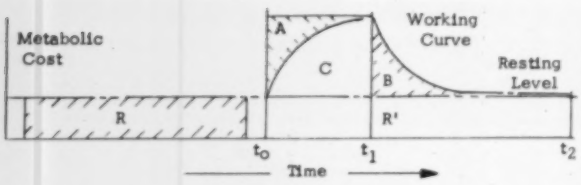

FIG. 4. Integral Method

The sample-bladder fitted to the gasometer is evacuated by a hand pump prior to beginning any measurements. Because of the diffusion of gas through the bladder, it is essential that the sample remain in the rubber bladder for as short a time as possible before being transferred to the analyzer. It is, therefore, either analyzed immediately after collection or transferred to a glass vessel.

Since the rate of flow apparently affects the reading of the oxygen analyzer, it is probably best to flush the sample through the instrument and take the readings at a zero rate of flow.

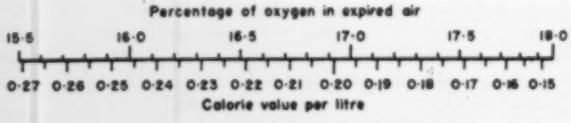

FIG. 5. Calorie Value Scale (Weir)

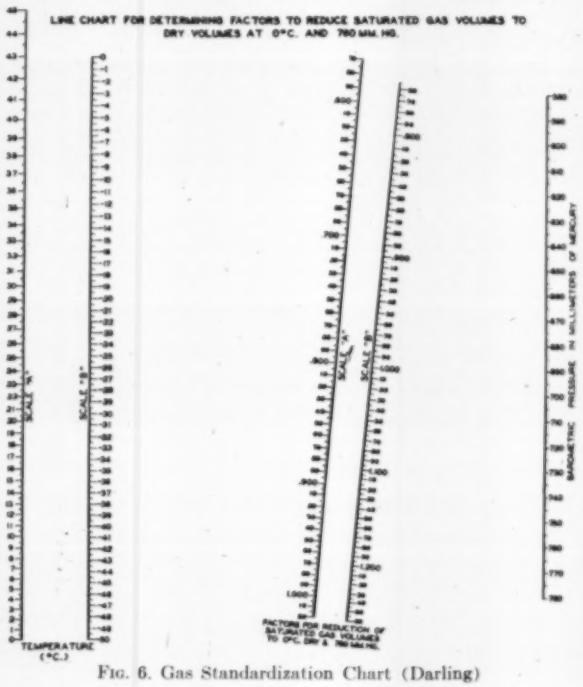
LINE CHART FOR DETERMINING FACTORS TO REDUCE SATURATED GAS VOLUMES TO DRY VOLUMES AT 0°C. AND 760 MM. HG.
TEMPERATURE (°C.)
BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

FIG. 6. Gas Standardization Chart (Darling)

SAMPLING METHODS

To determine the metabolic cost (work energy requirement) for doing a specific task, it is necessary to find the total caloric expenditure for the subject while doing the task and deduct from that the cost of maintaining the body functions without working. In this way energy requirements are relatively independent of the time in which the task is performed.

This can be explained graphically by Figure 3 showing the metabolic cost for the subject versus time. In the so-called "Partial Method" it is essential that the working sample be taken after the subject reaches a steady-state of oxygen consumption which will be several minutes after the task is started. This working sample is represented by the shaded area "A". From this must be subtracted the resting metabolism, "R", for a similar time period.

The resting metabolism should be obtained for the subject just prior to the working cycle. Precautions must be taken to ensure that the subject is in a resting steady-state and has not exercised for some time before the test is made. It also should be noted that smoking or eating before making the test is apt to change the resting metabolic rate.

In some cases it will be difficult to attain the steady-state during the work cycle either because the cycle is too short or energy expenditure within the cycle is very variable, or the task is so heavy that no steady-state is reached. Under these conditions the steady-state method described above can not be used; however the Integral Method (12) does not have this same disadvantage. This method developed by the Max Planck Institute, is illustrated by Figure 4 and is based upon the similarity of two exponential curves enclosing area "A" and "B" (15). The subject's data is recorded from t_0 to t_2.

The metabolic cost goes up from t_0 to the end of the task t_1 which may or may not be before the subject reaches a steady-state. During the next time period, t_1 to t_2, the subject's metabolism returns to the resting rate. Since the area of "B" is similar to the area of "A", the total metabolic cost is considered to be the measurable area of "B" plus "C" plus "R". The resting metabolic cost must be deducted, of course, so that the working metabolic cost is "B" plus "C" minus "R". It is essential that the resting metabolic rate is measured immediately before the working metabolic rate is measured.

	Resting	Working
Gas Volume		
1. Ampule No.	212	213
2. Temperature, °C.	25.5	26.0
3. Barometer Reading, mm	723.9	723.9
4. Gasometer—ending, Liters	5303.0	5384.6
5. Gasometer—starting, Liters	5244.2	5303.0
6. Gasometer—difference, Liters	58.8	81.6
7. Corrected Volume, No. 6×*1.043* meter constant	61.3	85.8
8. Barometer and Temperature correction factor	.841	.840
9. Corrected Volume, No. 7×No. 8.	51.55	72.07
10. Sample time—minutes. $t_0-t_2=$	7.0	7.0
$t_0-t_1=$		2.0
Gas Concentration		
11. Percentage of oxygen in expired air.	16.97	16.07
12. Caloric value of consumed air per liter.	.197	.242
Caloric Expenditure		
13. Calories per test *Caloric Value No. 12×Corrected Volume No. 9*	10.15	17.44
14. $\frac{\text{Working Cost}}{\text{min.}} = \frac{\text{No. 13 working sample} - \text{No. 13 resting sample}}{t_0-t_1}$		3.64

FIG. 7. Sample Data Sheet

Explanation of Calculations

Gas Volume

NO.

1. Identification number of the sample ampule.
2. Respiratory air temperature.
3. Barometer reading.
4. 5 and 6. Four and five are read directly from the gasometer and the difference between these two gives the quantity of gas for the test period.
7. Each meter has been calibrated by the manufacturer and it is necessary to multiply No. 6 by the calibration factor which is stamped on the meter.
8. Correct the gas for standard conditions; i.e. reduce saturated gas volumes to dry volume at 0°C and 760 mm. Hg. See Figure 6.
9. Corrected volume of gas for standard conditions.
10. Recorded sample time. See Figure 4.

Gas Concentration

11. The percentage of oxygen which is read directly from the oxygen analyzer.
12. The caloric value of the oxygen used by the body as obtained from the nomograph, Figure 5.

Caloric Expenditure

13. Calories consumed by the body during the test period as explained by equation.
14. The difference between the working and resting column gives the amount of energy required for working over and above the resting cost. In this case, the recorded times for the working and resting samples were both the same 7 minutes. If they are different, the rate of expenditure while resting must be multiplied by the duration of the working sample to obtain the estimate of the resting consumption. The rate of consumption is the metabolic cost divided by t_0-t_1 which is 2 minutes.

The "integral method" has been developed and tested extensively at the Max Planck Institute in Germany and is described in Dr. Gunther Lehmann's text *Praktische Arbeitsphysiologie* (12). There it is stated that the oxygen which is consumed after the work ceases is used to pay the oxygen debt in the body and in most cases this is exactly the same amount of oxygen as that of the deficit created at the beginning of the work.

The oxygen analyzer will show the percentage of oxygen in the sample of expired air. To find the caloric expenditure by the subject it is only necessary to refer to a nomogram developed by Weir, Figure 5 (19).

The volume of gas must of course be reduced to standard conditions of 0° Centigrade, dry, and atmospheric pressure of 760 mm of mercury. This again can be done by means of a second nomogram, Figure 6 (6).

So with the percentage of oxygen in the expired air and the volume, it is a simple task to obtain the caloric cost. An example is presented in Figure 7.

CONCLUSIONS

Mechanization of American industry has relieved the worker of many of the heavy tasks that he used to perform. In some cases the physical fatigue from muscular activity has been replaced by psychological fatigue from boredom caused by the monotony of the work. However, in many tasks in many companies it is still desirable to compare the physiological costs as well as the times for doing work.

Recently, equipment has become available to simplify the job of measuring the energy expenditure of the worker. This type of equipment is being used by doctors (8), Industrial Engineering students (1), agricultural engineers (5), and home economists in consultation with work-physiologists.

The cost of this apparatus is within the reach of a modestly equipped laboratory. The equipment can, if handled with care, be taken into a field situation. The gas meter, for instance, has been used in farm tractor riding research and has required only occasional cleaning.

The possibility of the Industrial Engineer making decisions based on physiological costs rather than on time alone is most encouraging. The techniques described here are progressing well beyond the laboratory stage and as noted have been used in actual work situations. However, many of the problems that the Industrial Engineer faces could and should be answered in the laboratory. It, therefore, behooves industry to support some of the research that can be done in this area to establish method improvements and principles of motion economy firmly on a physiological as well as a time basis.

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Work Design: A Philosophy for Applying Work Principles[1]

by **GERALD NADLER**

Professor and Head of Department of Industrial Engineering, Washington University

MOST Industrial Engineers agree that industrial engineering concerns the work of people, both by themselves and in conjunction with other people and equipment (a system). Taylor started this activity by trying to find increases in the productivity of workers on specific jobs (4). Time study was his main tool. However, he recognized there were other problems which centered about the work of the group, the department, the section, and even the whole organization. Thus came the areas of production or services planning and control, facilities layout, materials and information handling, and so forth, all concerned with work systems at levels beyond the individual work place.

Yet the final results of Industrial Engineering show their effect at the individual work situation or group of work situations, and it is this point from which must come almost all the basic data required for other Industrial Engineering techniques.

GILBRETH'S PHILOSOPHIES OF WORK

The Gilbreths made the greatest contribution to the study of work through their motion study developments. Their fundamental philosophy, that work should be studied qualitatively before any quantitative measures are applied, is almost universally recognized as the correct approach to work problems. To carry out this philosophy, they developed motion study, which included many techniques still in use in one form or another. The format of many of their techniques, like therbligs and the principles of motion economy, indicates their use as design tools. Even their phrase "the one best way" should be interpreted as meaning that "there is always a better way."

In addition, the Gilbreths felt that the "idea of the one best way was dynamic. . . . It was bound to be because it implied worker participation (everyone's participation). It took account of differences as well as likenesses—of satisfactions as well as skills."[2] The term work simplification, which took both the techniques and participational philosophies of motion study, was developed to describe a greater participational emphasis which was felt to have been pushed aside when motion study was applied. The human factor has received much more attention recently. Job enlargement has become a term that signifies the assignment of more responsibilities to individuals rather than less. A recent article summarizes the human problem when it points out that "Many personal and productivity problems in industry stem directly" from the systems and methods being used (1).

PRESENT PRACTICES AND BELIEFS EMPHASIZE IMPROVEMENT

However, motion study and work simplification (other synonyms include methods study, methods improvement, and methods engineering) have been and are being applied almost universally for the improvement of work, i.e., the development of solutions to problem or difficult situations concerning existing work. Perhaps this developed from the rather narrow interpretation placed on the word "motion" in motion study, and on the obvious improvement implications of the word "simplification" in work simplification. Perhaps there was so much work that needed improvement. Even though the Gilbreth philosophies are still valid, the application and general impressions generated by these terms have left a most definite improvement flavor. Management and laymen consistently refer to improvement and study of existing work problems or difficulties when these phrases are used. The overwhelming emphasis on improvement has been dramatically illustrated even recently by two articles on work simplification (2) (5).

Improvement has been important and will continue to be a part of work and Industrial Engineering philosophies. Industrial Engineering owes much of its development and existence to the improvement applications of motion study and work simplification.

Yet using the improvement approach for applying work principles leaves much to be desired.

[1] The author wishes to express his sincere appreciation to his many Industrial Engineering colleagues in Washington University, other educational institutions, industry, consulting, and publishing who so kindly reviewed the preliminary draft and offered many suggestions. They will recognize many of their comments herein.

[2] Private communication from Mrs. Gilbreth to the author, 1958.

The improvement concept tends to emphasize and foster a somewhat negative philosophy. In the first place, improvement assumes a job exists. A job must be present before the principles are applied, or "improvement" can be expected.

Secondly, improvement tends to give the impression that any change is satisfactory. People become satisfied when they have made an improvement, even when the change is not as good as it could have been. Too often, the work methods which remain are defended with the statement, "This is necessary," thereby neglecting attempts to make further changes in the work.

Thirdly, improvement almost always implies, and literature prescribes, that something should be "wrong" with the work activity. Emphasis is placed on bottlenecks, high cost operations, operations "involving a lot of walking," high scrap centers, or other trouble spots before applying work principles.

Fourthly, improvement implies a limitation on the participation of people in applying work principles. There is an attitude that many people cannot understand some of the work concepts. Then, when a problem arises, and an "improvement" is required, little or no time exists for the proper indoctrination of those involved; after all, "we have to hurry to find an answer to the problem." Thus, techniques are not explained, and participation is forgotten, not utilized enough, or creates the negative "resistance-to-change."

Fifthly, some definitions are restricted, and tend to indicate too narrow an outlook about work. For example, work simplification is defined by one school of thought as "The organized use of common sense to find and apply better ways of doing anything (5)." In addition to implying that management isn't organized or doesn't have common sense enough to find better ways, today it takes more than common sense to plan or design complex work arrangements and functions. Now, common sense tells us that we should be using new techniques and philosophies; common sense will still be coupled with these new techniques to solve the wide range of work problems confronting Industrial Engineers, and to translate the new complex tools and their results into understandable language for utilization by others.

Occasionally, and too infrequently, a few statements have appeared concerning the use of work principles for the planning or design of work.

NEW PROBLEMS

New business and industrial situations indicate the inability of the improvement concept to handle the difficult work activities arising. The work people perform is undergoing radical changes: more machines are being used, the operator has fewer repetitive activities to perform, electronics assist in making decisions, and so forth. These changes emphasize three problems for which a different approach with work principles is needed:

1. The design of work for people operating more complex equipment (automation for factory or office) is more critical and important because of the greater investment per person. Therefore, there is a great need for technological staff to design work adequately for the fewer persons required.
2. Operating and maintenance personnel must make many process and work decisions in the new non-repetitive situations. Therefore, such personnel must be adequately prepared, through training in work principles and design, to make these decisions at the point of action.
3. With an increased number of manual work job shops, which will result as mechanization and automation increase, finding better ways for present work in all organizations must be emphasized at all levels (product design, process, work).

These problems indicate the need for reaffirmation and new groupings of the Gilbreth philosophies, and for the development of new concepts and a new term to fit the framework of new problems. The phrase Work Design accomplishes this. Many businesses recognize the design concept as more important than the improvement function, because a large proportion, even the majority, of their income comes from products and services not in existence as recently as fifteen years ago. Now they must consider Work Design as essential to make certain the work (and product specifications) associated with these new products and services is *planned* properly before the activities start.

WORK DESIGN DEFINITION

Work Design is the systematic investigation of planned and present work to formulate the easiest and most effective systems and methods.

"Systematic investigation" includes several important components: a step-by-step scientific approach, the full involvement of all levels of personnel in the activities of Work Design, the use of proper tools and techniques.

"Work" means any organization or company activity (direct or indirect, factory or office, service or production) where people are involved. Work could even include past, as well as present and future activities. The work can take place at any location or in any industry, and be performed just a few times, even once.

"Easiest and most effective systems and methods" means there should be no unnecessary work, the best arrangement for the remaining work, the design of the "best" system in terms of the conditions of the organization and people, a proper utilization of these work systems, and an establishment of adequate performance standards for further use in Work Design and Industrial Engineering. Such performance standards are essential in Work Design to provide information for the necessary predictive function expected for any planned activity. Such predictions are even more important for the new types of non-repetitive work being established.

Work Design uses the mechanistic techniques of motion study and time study (and other related areas, like plant layout), the participational concept, and the new techniques and concepts as building blocks to evolve a more

inclusive philosophy. It helps keep pace with the growth of Industrial Engineering into its more mature status.

HOW WORK DESIGN OPERATES

Work Design is an operating philosophy, and not a theory of work. A good theory of work would be helpful to explain and modify Work Design. For example, there should be a definitive relationship of work and its performance to the sociological, economic, organizational, and psychological factors involved in both management and the individuals performing work.

OPERATING PHILOSOPHIES

Work Design is highly dependent on developing proper mental attitudes and personal viewpoints. The human being is of great concern, in both participation and application. Work Design can never be considered as just a set of techniques or tools to be used in the study of work; this paper will not even discuss the techniques of Work Design.

In that sense, the bases for Work Design are its operating philosophies. Management should adopt these philosophies to make Work Design most effective, and to make their own approach to management problems more effective.[3]

Work should be designed before it is performed. This principle seems almost too obvious, yet there are several compelling reasons for making it one of the first philosophies.

As the investment per worker increases, work must be planned and designed as thoroughly as the design of a new product or the location of a new plant. It is no longer desirable to assign work to anyone without prior design. Machine systems designers are not trained to do this; this is the role of Work Design and Industrial Engineering. A Work Design specialist should be on product engineering or company planning group; this is where he belongs. And these Work Design philosophies help place the specialist in a better light with his equipment design colleagues.

Management needs to recognize this philosophy of Work Design for another benefit: it assures a continuous, active program in an organization when new installations, new products, and new services, which every organization develops, utilizes work planning and design. Work Design, used so often and profitably, is kept active in all its facets, including betterment and improvements. Thus, a well-balanced program is developed. When Work Design is applied in the planning and original system design stages, two basic concepts are involved:

1. Design of the product or services to maximize the utility of the end result to the consumer. Such designs should result both in better equipment, machine tool devices and services to permit the proper utilization by the customer's employees, and in better consumer-product or service design to permit the general public owner to utilize his efforts with his purchases in the best manner possible. The function is not the only consideration in product and service design.

Human engineering which is concerned with the efficient operation of man in man-machines systems, developed basically from military requirements. Such data are desirable with the Work Design philosophy and the Industrial Engineer's greater breadth of responsibility (consideration of more plant and organization operating characteristics), to achieve optimum product and work designs.

The effects of using this philosophy will be felt in many functions of an organization: the sales department can have an effective presentation. Advertising can be more poignant. Field engineers will have fewer cases of dissatisfaction. Feedback to design will be usable in total, including human performance problems.

2. Design of product or services to minimize the cost and effort of producing the end result within the organization. Work Design must take cognizance of the abilities of the available people, loyal in most cases, but differing in abilities, likes and dislikes (some like repetitive work, others like more job responsibility), and so forth. Few Industrial Engineers look beyond the bounds of the department or manufacturing section. Now, many facets must be considered, such as materials; other companies' designs, materials and services; purchasing practices; parts storage systems; drawing files; parts standardization; and so forth. The entire work function is brought into proper perspective.

A planned program of making betterment changes, even with "well-functioning" and "low-cost" activities, is essential to continued higher productivity and profit increases.[4] This statement is the operating approach to the Gilbreth's philosophy of "there is always a better way" for work.

"Low-cost" usually means either a low unit cost, or a low proportionate cost in relation to other costs. However, either case may still involve many dollars, even millions. Every cost in an organization should be studied for potential savings. The manual activities involved in any cost may be only a small part of the work; yet it is usually the key to the entire cost, through which Work Design can study the whole activity.

Even "perfect" or well-functioning activities should be challenged. *All* activities are susceptible to further Work Design study.

To be effective, each supervisor should be trained in all

[3] In the minds and practices of some Industrial Engineers, most of the following philosophies are common procedures within the existing terminology of motion and time study, or work study. Certainly, this is the case for the author. However, conversations with most Industrial Engineers, laymen, and management people, as well as a review of almost all the literature give the opposite picture of the terms—one of improvement and narrowness in work thinking. A new phrase, more descriptive, more related to the feelings of advanced Industrial Engineers, more inclusive of new philosophies, and more conducive to indicating the correct direction for applying work principles is needed—that is Work Design.

[4] The material in this operating philosophy came into sharper focus after discussion of Work Design with several persons, especially Mr. Art Spinanger, Associate Director of Industrial Engineering at Procter and Gamble, concerning the planned changes concepts in use there, and Dr. N. A. Dudley, Head of the Engineering Production Department at the University of Birmingham in England, in describing the betterment program at Joseph Lucas, Ltd.

the Work Design philosophies and techniques to help him select a realistic objective concerning the savings to be made in the coming period (usually a year) for some well-functioning or low-cost activities. Thus, productivity indices for the overall organization are established. The ideal goal is to eliminate all the cost. In companies using this approach, the average achievement per supervisor amounts to thousands of dollars. Little expenditure is required to achieve these results.

Some companies include in this approach a critical review of products and designs to find savings in material and specifications.

Changing products, equipment, and processes make it imperative that Work Design help *plan* the associated work component changes. Thus the same benefits expected in Work Design with new products and services will be realized.

Change, planned betterment changes, should be a way of life in every organization. This is the only way the organization can really offer security and stability. Managements have recognized this for products and equipment; now it must be recognized for work.

The work system to be used should represent the minimum departure, compatible with the condition restrictions, from the ideal system for ideal conditions. Under ordinary circumstances, "ideal conditions" mean a large volume for the product or service. "Ideal system" would involve no work to produce the large volume of the ideal conditions. This philosophy, therefore, establishes the goal or objective for original designs of the first philosophy, and the betterment changes of the second philosophy.

This philosophy, to go even further, should be used for the third type of Work Design situation: an actual problem, where an "improvement" is necessary. The complete range of situations, then, that may be encountered is:

1. Design of work before it is performed.
2. Betterment changes.
3. Problem situations (like bottlenecks, overtime, etc.) where it is necessary to improve the present methods.

Although this goal may sound too theoretical, it is extremely practical to help the organization and its people achieve continual productivity increases.

Determining an actual ideal work system to use as a goal or objective in a specific situation requires imagination and a completely open mind. The designer of work to be performed must free his thinking from conventional processes and methods, and develop a product, service and/or work system which represents the ultimate or desired system. Betterment and improvement situations require forgetting what is being done to use this same approach to develop an objective, the ideal system; these situations demand that any betterment or improvement should be approached as if the work were not being performed at all. Then, in design, betterment or improvement situations, the actual work system to be used should be as little removed from this ideal system objective as the actual conditions will permit. For example, production of a product is considered ideal when automation is developed; therefore any situation (design, betterment, or improvement) involving production should have an actual automation scheme planned to use as the objective. Or an office situation should have an automatic and integrated data processing plan for use as the objective.

This philosophy emphasizes positive goals and objectives in place of the usual situation where finding a better method frequently becomes the goal. The "ideal" goal orientation becomes the heart of Work Design planning, betterment and simplification activities.

People, their abilities, and their talents are an integral part of Work Design. Almost every philosophy of Work Design includes reference to and involvement of all personnel levels of an organization. People doing the work, and those who will be in charge of the work are necessary in Work Design.

People take a greater interest in their work when they understand the concepts and principles of work. Explaining and training in Work Design and the broader work and company problems make people take an interest in their work. This, plus the correct amount of responsibility, individualism, job rotation, and physical comfort, does much to eliminate boredom, monotony and fatigue.

This approach makes Work Design results more realistic and includes the best thoughts of everyone. In addition, such an approach helps develop people to their fullest extent, and make them more valuable to the organization.

All the people in an organization will not design work or apply the principles or techniques; yet the philosophy and at least, the concepts of most techniques and, at best, the details of some techniques can be presented in an understandable fashion. Otherwise it will be difficult to have them accept the results of the techniques. This is true for all persons in the organization, from the top executive and foreman, to workers (at least the concepts must be understandable to the workers' agents).

Work Design training emphasizes the positive aspects of the contributions of people rather than the usual negative approach of overcoming resistance to or resentment of change. Experience creates knowledge and the people of an organization have much experience. Through Work Design as much as possible of this experience can be turned to the design and betterment functions, as well as to improvement.

Greater productivity, achieved by the cooperation and participation of everyone, is a worthwhile objective in itself. This basic economic truth should be brought up-to-date in terms of present day situations. For example, the Committee for Economic Development, a group composed of one hundred and fifty outstanding business men and educators, recently noted, when reviewing the economy as a whole, that the average percent increase per year in

wages since 1946 has been about twice as much as the average percent increase per year in productivity (5 to 2½ percent). Although the Committee inferred that the difference was inflation, it is not the purpose of this paper to comment on the socio-economic aspects of labor's point of view in continuing this situation through increasing demands. The problem will have to be solved by either greater increases in productivity, reduced demands for higher total labor costs, or both.

Thus, it is *always* good to increase productivity, and Work Design reiterates this concept through this philosophy.

More qualified and better training staff personnel are required. Two points should be made. To achieve the first three philosophies, many new tools and complex techniques will be needed. For example, the powerful tools of mathematical programming are becoming essential for developing the ideal system, or goal. Staff personnel will have to be better versed in psychological, physiological and ergonomic concepts.

Secondly, the Work Design specialist must be able to translate and simplify the results and concepts of these newer tools so they can be explained to and, in some cases, used by line supervisors and workers.

When one considers the qualification level of personnel usually involved in applying work principles, it is easy to understand why Work Design includes such an operating philosophy. Management must understand that Work Design staff activities are important and necessary at a high level to assure a successful program. As much as Work Design depends on the great potential latent ability of the organization's personnel, it still required good coordination and planning on the part of staff to tap this excellent source.

Closely related Industrial Engineering areas are more logically included in Work Design. Plant layout and materials handling are closely related to Work Design. For example, the methods of work at individual work places should be designed with consideration for the means of moving the material between each work station and the location of each work station in the entire arrangement.

Work Design includes work measurement, which is essential to perform most of the predictive functions of Work Design. Expected performance predictions are required, and work measurement must be adapted to serve predictive aspects more than ever, and new techniques must be (and are being) developed to help predict results *for* the new type of work becoming more prevalent in all organizations (3).

In effect, Work Design becomes the term applied to motion study, work simplification, work measurement, plant or facilities layout, and materials handling.

Just as quality control, production planning, and production and inventory control deal with specifications of machine capabilities, processing, scheduling and work or purchase orders, so Work Design should deal with the performance specifications and predictions for human activity.

THE TYPICAL WORK DESIGN PROGRAM

There are several significant new items in a Work Design program, although there is some similarity to usual work study programs. Each organization will have some program differences based on its own conditions. Thus, optimum or practical programs in Work Design vary, and are usually dependent on cost and time for application, and long range objectives. For example, an aircraft corporation with low volume would not be expected to design forthcoming work with as much detail and breakdown as would a manufacturer of small electric motors. However, re-education of all personnel to think and act in the Work Design philosophical framework is the key to a successful program.

The various activities of a Work Design program are not mutually exclusive, nor performed separately. On the other hand, certain activities are performed once and then reviewed on a periodic basis. Many details are omitted, and the program factors, subject to much interpretation and expansion when being implemented, are reviewed only briefly.

EDUCATION

Work Design indoctrination must start with every person in top management, and continue through and include the workers. The amount of education time varies for each level of an organization. For example, one top management received a ten three-hour session program, the next levels of management fifteen sessions, the staff levels twenty sessions, and the workers a simplified program of five sessions.

The case problems in all training sessions should be real work problems from the individual's own work areas. This creates an excellent effect on and stimulation for all levels of the organization. The reaction of supervisors, middle management, and workers is most amazing when the president of the company, for example, is on the shop floor making a product process chart.

Work Design training sessions should have horizontal representation of management, staff, and workers, rather than vertical alignment within a function. In some cases, the "teach-as-you-go" concept is used with the workers because of time and other limitations. In still other organizations, the product is somewhat complex, like in an aircraft installation. Here, the training programs are much longer for those who will be working with the product planning and design staffs.

Management should instill the Work Design philosophies throughout the organization by means other than the educational program. For example, some companies have a bonus program for departments, a weekly or monthly poster campaign, or special cost reduction programs which should be integrated into Work Design.

In newsletters, posters, or other publicity material, the Work Design philosophies should be stressed. Slogans should be developed to carry this out, such as:

Plan first—make better next.
People + philosophy + planning = pleasant productivity.
Work designed is work saved.
Better your work.

MANAGEMENT POLICIES

Probably the most important policy related to employees is that no employee will be laid off as a result of Work Design activities. Other such policies are necessary and they need not be repeated here. A benefit of Work Design is the reduced need for applying these policies; work designed does not produce the difficulties of work improved.

The internal operation of Work Design requires management to make some policy decisions concerning how the function should be organized. Should there be a Work Design department? To whom should the function report? Should the responsibility of supervising all the Work Design activities be placed in an individual or in a committee?

Because Work Design should be used throughout the entire organization, the function must report to someone or some committee with broad overall responsibility for more than just the manufacturing operations (like the president or the executive vice-president, or a committee from among those reporting to the president or executive vice-president). This serves the double duty of still further management indoctrination in this philosophy, and adequate Work Design direction across the board.

What groups should have a specialist as a member—development or project engineers, sales groups, office and accounting groups? In such groups, the work designer would assume the responsibility for approving product and service designs and changes in relation to customer wage and work content. He would also be responsible for initiating betterment changes and ideal work system concepts within his group at every possible opportunity. The tools and techniques used by the work designer will vary considerably from situation to situation. In an engineering or product design group, he may need to use human engineering principles in conjunction with production flow concepts to achieve optimum consumer and production-cost designs. In an accounting group, data processing concepts will assume greater importance.

One organization established an interesting policy. Product design responsibility is removed from design within a certain period after the original specifications are given to the production planning function. Then production planning assumes the responsibility for design changes. Here, a work designer was placed in the product design group, and another in production planning. There is close cooperation during the overlapping period when design changes must still be approved by the design function.

Management should state the positive philosophy of Work Design as a separate policy, and even as part of its creed for the organization. This provides good stimulation to the entire organization.

WORKSHOPS FOR APPLICATION

The members of a workshop are those who were together in an educational program. With the horizontal personnel assignment, the workshops are ideal for discussing design, betterment, and improvement problems of the organization.

Each workshop group usually meets once a month. Their purpose is to discuss general and mutual problems, get refreshers in Work Design and new techniques, and to review the application of Work Design as a whole. Subcommittees of each workshop group are assigned to specific projects. Each person is still responsible for applying Work Design in his own area. As necessary, special subcommittees crossing workshop group lines can be established to take care of new interdepartmental work to be done in the future and other overlapping work situations. This arrangement creates tremendous forces to apply Work Design in all facets of design, betterment and improvement.

By organizing the application activities on the workshop basis, with the Work Design function as the principal coordinator, it is possible to obtain the maximum cooperation from all persons in the organization, with a rather small average amount of time spent by each person in meetings.

AUDIT AND REVIEW

If the Work Design function reports to a committee, this aspect is part of the committee's activities. However, if the Work Design function reports to an individual, then an audit and review committee might be desirable.

This part of the program is essential at the beginning of a Work Design installation to check on the usage of the important philosophies. The program should veer as little as possible from the goal concept of the ideal system.

A Work Design program is difficult to evaluate directly; for example, how is it possible to "see" or detect adequate design of work before it is performed? However, there are some gross and indirect symptoms of a good program: more productivity, more profit, better morale, etc. There are several actions which can be taken to assist in audit and review.

A Work Design review panel, independent teams and/or experts would review the designs established by the design functions (similar to product design review boards or panels). They should also make reviews of improvement projects. A sampling basis should be used to review the activities of the workshop groups. Such reviews of the entire program help create suggestions to management and the workshops for further action and changes.

APPLICATIONS RESEARCH

Work Design's philosophies, especially the first, second, and third, indicate a strong need for research into new application concepts for an individual organization, and a review of available literature and research to make applications better within the organization. For example, ergonomics has been receiving attention in European countries. Ergonomics is the study of man and his many different working environments. A planned research attack must be part of a Work Design program to make available such information to the organization.

Similarly, investigations into operator performances through UNOPAR studies are developing information necessary for designing proper control and machine equipment, and for predicting the output characteristics of a specific work design. New refinements and applications of mathematical programming tools will be available for more complex Work Design analyses and evaluations. For example, Professor Ken Barten at Washington University is developing a mathematical model to simulate and evaluate plant layout alternatives. There are much research data concerning the relationship of work to physiological, economic, sociological, engineering and organization concepts.

Each company should continually bring its special problems to the attention of research agencies, and some may even want to undertake some research. For example, a problem of importance to Work Design is to find a mathematical model for operator performance which can be used to simulate the many different conditions to be found in work; this model would be a priceless asset to planning, betterment, improvement and predictive objectives of Work Design.

APPLICATIONS APPROACH

A definite scientific approach or logical procedure for finding Work Design answers may be stated in many ways, and with varying number of steps. The Work Design approach, similar to other logical procedures, uses words to emphasize its philosophies, and has nine steps for developing solutions:

1. Determine the objective. Isolating the activity of interest for design, betterment, or improvement and knowing why it should be studied is necessary. Knowledge of the gross limits to the type of solution, and the tentative means by which the solution can be found help to make a good start.
2. Get facts. Many facts are available, but it is essential to get all the information about proposed or presently used material or input, product or service design, sequence, equipment, method, and work content and arrangement.
3. Develop possible ideas. Check lists and group action develop many ideas. The ingenuity and imagination of everyone is important here. This step should develop the ideal system and method as the goal for evaluation in the next step.
4. Select the best idea. Based on the condition limitations from Step One, the "best" idea or group of ideas is selected as being the closest to the ideal system proposed in Step Three.
5. Design the details for the work. This involves the expansion of the idea or ideas into operating specifications.
6. Review the Work Design. This step is especially important when new work is being designed. It is helpful for finding more betterments and improvements by forcing another comparison with the ideal system.
7. Test the Work Design. A test, if possible, helps iron out possible sources of trouble.
8. Install the work systems and methods. Many actions are required to put the new procedures into operation, including training and follow-up.
9. Establish performance predictions. Has the goal of Step One been reached, and what output or operating characteristics can be expected from the new work situation?

APPLICATIONS OF WORK DESIGN

Work Design installations have taken many formats, and the types of organizations in which these activities have taken place are varied. Some are worth mentioning to demonstrate general application situations.

1. One job shop of three hundred unionized employees making electrical distribution products for industry had a complete program of Work Design. A Work Design specialist was not assigned to the various functions of the organization. The Work Design function reported to the executive vice president. As needs arose in the sales, design or accounting functions, the executive vice president placed a Work Design specialist with the specific group.

A foreman, who wanted to improve the work of a crew of two men, was placed on a subcommittee with the foreman of the department from which the in-process work came, an Industrial Engineer, and the two workers. The output of this crew was around forty-five units a day. The new method, involving changes in the preceding department, should produce 115 units a day. A portion of this change came from a reduction of time spent by the men in various personal time activities. The development of every component of the final time standard was reviewed with the foremen and crew members before the standard was installed. Standard production was achieved within three days after installation, incentive earnings were earned thereafter, and these two men, applying Work Design to other work situations in the department, became good-will ambassadors for the Work Design program.

Another workshop subcommittee, composed of the foreman who would be in charge of the work, the foreman from the punch press department, and an Industrial Engineer (as needed, several key working personnel were included), designed the layout, handling, and methods for producing, at the lowest possible cost, a new product for which the company would pay patent royalties to another company. After making changes in product design and materials as well as designing the layout, methods and equipment, the final total cost (including the patent royalty) was less than the cost of manufacture for the company to which the patent royalties were paid. After six years and betterment program changes, this cost situation still exists.

2. A small company of thirty employees had one supervisor who set up the methods for a new job or product. He was given basic training in Work Design. Training the operators was done on a "teach-as-you-go" basis. Discussions were held concerning what jobs should be established for a product and how they should be performed. They used this information for betterment of work as they were performing it, and for the design of later new work. Because the relative cost of a Work Design specialist would have been too high, the supervisor and president were taught how to review original product drawings before any parts or components were made or ordered.

3. A company with one thousand union employees made prod-

ucts to customer specifications. Occasionally, some product would "catch on" and might become saleable to other concerns. Heavy emphasis was placed on incorporating Work Design philosophies into product design groups. However, an interesting result from the top management education group was the greater emphasis on the betterment function; they learned about how much could be saved.

After four years, the workshops are still an important activity of the company. Previous programs, like "Mr. Bonus Saver of the Month" and suggestion systems, have been integrated with Work Design.

4. A department store, with 3500 employees, included in the Work Design program all the people in the operating divisions. The complete layout and methods for a new service center to serve as a warehouse, receiving and delivery center were established before any architectural design work was permitted. The service center office (a communications center, a major appliance and a radio repair center, and the location of the warehouse clerical activities) used Work Design to design the systems for what *must* be done rather than for what was being done in the previous locations. A usual result of Work Design found the managers, secretaries, and clerks suggesting most of the changes.

5. A company employing seventy-five union persons used Work Design and the workers' participation to develop automation. Using an ordinary product process chart, the lead man and several of the workers (trained mainly by "teach-as-you-go" methods) developed a completely automatic process, from coil stock to assembly, for producing and processing tubes through a mill. The Work Design specialist was a product designer. Because the company's costs, through automation, were lower, about three years ago, they felt they could undersell other companies making a product which had a great deal of competition. Now they have become the largest producers of this product in the entire midwest, have extended their operations three fold at the present location, and have located new plants strategically in their market area.

THE OUTLOOK

Work Design offers an excellent opportunity for a complete and unified program concerning work. The various facets of design, betterment and improvement are continuously being stressed thereby insuring an active and long-term program. Management now has a procedure for applying work principles which meets the requirements for all managerial functions: planning (design of original work), operating (improvement and betterment), and control (betterment), all oriented toward the objective of the ideal work system. Also Work Design emphasizes the true place for applying work principles: the best betterment or improvement starts with the best design of original work.

Work Design is a dynamic and changing field. It is engaged in developing and applying new techniques and expanding philosophies; it is not concerned with the sanctity of a technique or two, a particular point of philosophy, or a name.

Through this approach, the principles of work can be utilized more effectively, the objective of higher productivity realized more fully, and the professional status of Industrial Engineering advanced more satisfactorily.

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Double Sample Estimation in Work Measurement

by MORTON KLEIN

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SINCE the introduction by Tippett (11) of the ratio-delay procedure for estimating the relative frequency with which delays of different kinds occur, there has been an increased interest in statistical estimation techniques on the part of those engineers concerned with work measurement.

In most work measurement problems there are two groups of components which lead to observations which vary. One is composed of the errors resulting from the use of a less-than-perfect measurement system, e.g. in a time study the observer and the timing instrument fall in this class. The second component is the variation in the production system which is being studied. It is presumed to be caused by the host of physical, methodological, psychological, sociological and economic factors which are known to be capable of affecting the performance of a worker-production system (5). Usually, engineering efforts are made to reduce the variation caused by both of these sources; there are generally some limits beyond which it is uneconomical to continue these attempts. However, after all engineering work has been completed, the residual variation may still be too large for particular situations; that is, a certain kind of decision may call for an estimate of a performance characteristic with a maximum prescribed error which is smaller than that which exists naturally. It is well-known that uncertainty related to these performance characteristics can usually be reduced by the simple expedient of taking additional independent observations, i.e. making additional measurements. The question which then arises is how to take the observations and how many should be taken. The purpose of this expository paper is to describe some double sample techniques which can be used to obtain estimates of some of these performance characteristics when the maximum allowable error can be specified in advance. Two work measurement problems will be considered.

PROBLEM 1

The first problem of interest is to obtain an estimate of the mean time taken by a worker to complete a well-specified operation.

In order to use the statistical techniques which are available for this problem, two assumptions are required:

1. The worker-production system is such that, each time the operation is performed, the system is essentially the same. This is usually called a "state of control"[1] or a condition of "technological stability" (1) (8).
2. The random variable of interest, i.e. the time taken to complete an operation, has a normal distribution.

The first assumption is a fundamental requirement for the use of most statistical procedures; if reasons exist for doubting that the system fulfills this condition, then none of the following techniques are appropriate. The second, although required for exact interpretation, is not absolutely necessary provided that the underlying distribution is not too far from the normal.

The requirement for an estimate of given precision is commonly made specific in terms of a 100 $(1-\alpha)$% confidence interval; for this problem, if μ denotes the mean time, a probability statement of the form given below is desired:

$$(1 - \alpha) = P\{G_1 \leq \mu \leq G_2\}$$

where G_1 is called the lower value of the confidence interval, G_2 the upper value of the confidence interval and $L = (G_2 - G_1)$ is its length; $(1 - \alpha)$ is called the confidence coefficient.

The above statement is interpreted as meaning that with probability equal to $(1 - \alpha)$ the random interval (G_1 to G_2) will contain the true value of the mean. For a fixed value of α, the smaller the interval the more precise the estimate.

It is convenient to consider two cases for this problem.

CASE I

The standard deviation (σ) of the distribution of the random variable is known.

For this circumstance a standard procedure is to take n independent observations $(X_1, \ldots, X_n)$ on the system and to compute the upper and lower values of the con-

[1] Criteria and methods for deciding that a "State of Control" exists for this problem are much the same as those used in statistical quality control work. Some are described in texts such as Grant (6).

fidence interval by

$$G_1 = \bar{X} - K_{\alpha/2}\sigma/\sqrt{n}$$

and

$$G_2 = \bar{X} + K_{\alpha/2}\sigma/\sqrt{n}$$

where

$$\bar{X} = \frac{1}{n}\sum X_i$$

and $K_{\alpha/2}$ may be obtained from tables of the standard normal distribution as that value satisfying the equation

$$\alpha/2 = \int_{K_{\alpha/2}}^{\infty} \frac{e^{(1/2)t^2}}{\sqrt{2\pi}}\,dt$$

If the length of the interval is prescribed, ($L = L_0$ say), the number of observations (n) required to yield such an estimate is given by

$$n = \left[\frac{2K_{\alpha/2}\sigma}{L_0}\right]^2 \qquad \text{Eq. 1:}$$

and the estimate is

$$\bar{X} \pm \tfrac{1}{2}L_0$$

Since n must be an integer, it is usually taken as the smallest integer which is larger than the value computed from Eq. 1. This has the effect of yielding an interval having a slightly higher confidence coefficient than originally specified.

CASE II

The standard deviation (σ) is unknown.

If $X_1, \ldots, X_n$ are the independent observations on the system, the corresponding upper and lower values of a confidence interval are

$$G_1 = \bar{X} - t_{\alpha/2}s/\sqrt{n}$$

and

$$G_2 = \bar{X} + t_{\alpha/2}s/\sqrt{n}$$

where

$$s = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1}}, \text{ is an estimate of } \sigma,$$

and $t_{\alpha/2}$ is analogous to $K_{\alpha/2}$ and is obtained from tables of the Student's t-distribution with $(n-1)$ degrees of freedom.

For this case, the requirement for finding the number of observations which will yield a confidence interval estimate of pre-assigned length cannot be satisfied by as simple an expression as Eq. 1. where σ was known; the equivalent calculation would have n as a function of s which is random. In fact, Dantzig (4) has shown that it is *impossible*, no matter what procedure is used, to determine *in advance* the number of observations needed for an estimate of this kind if the standard deviation is unknown.

Since a lack of information, namely that about σ, is the source of our difficulty with this problem, it is natural to consider a technique which involves taking a preliminary sample to gain information and then using the knowledge obtained from this sample to help decide how many more observations (if any) should be taken to get the precision desired. This kind of sequential decision procedure was first developed by C. Stein (10) for the problem under discussion.

STEIN'S TWO-SAMPLE ESTIMATION PROCEDURE

The following steps may be taken to develop a 100 $(1-\alpha)\%$ (or better) confidence interval estimate of fixed length of the mean of a normally distributed random variable.

1. Take a sample of m independent observations.
2. Compute

$$s^2 = \frac{1}{m-1}\sum_{i=1}^{m}(X_i - \bar{X}_m)^2$$

where

$$X_m = \frac{1}{m}\sum_{i=1}^{m} X_i$$

3. a. If

$$\frac{2st_{\alpha/2}}{\sqrt{m}} \leq L_0$$

the first sample size is sufficient and the estimate is given by

$$G_1 = \bar{X}_m - t_{\alpha/2}s/\sqrt{m}$$

and

$$G_2 = X_m + t_{\alpha/2}s/\sqrt{m}$$

where $t_{\alpha/2}$ is obtained as before from tables of the Student's t-distribution with $(m\text{-}1)$ degrees of freedom.

b. If $\dfrac{2st_{\alpha/2}}{\sqrt{m}} > L_0$

take a second sample consisting of n independent observations computed according to

$$n = \left[\frac{4s^2t_{\alpha/2}^2}{L_0^2}\right] - m$$

where $[a]$ denotes the smallest integer not less than a.

In this case, the interval is given by

$$\bar{X} \pm \tfrac{1}{2}L_0$$

where

$$\bar{X} = \frac{1}{m+n}\sum_{i=1}^{m+n} X_i$$

It can be shown that the confidence coefficient $(1-\alpha)$ associated with the above interval is greater than or equal to that required by the problem.

It may be noted that one may make an arbitrary choice for the size of the preliminary sample (m) in Stein's procedure. However, it is clear that if m is taken to be too large, there will be no requirement for a second sample. On the other hand, too small a value of m will not yield very much information and will result in large second sample sizes. If some information about the standard deviation is available, a rough guide (see Hodges (7)) may be used to choose a value of m such that the expected total sample size is minimized if the information is correct.[2] Thus, if σ^* denotes an *a priori* estimate of the standard deviation, the following approximate formulas are available:

Confidence Coefficient $(1-\alpha)$	First Sample Size m
.99	$5+20.0(\sigma^*/L)^2$
.95	$4+10.5(\sigma^*/L)^2$
.90	$3+7.1(\sigma^*/L)^2$

PROBLEM 2

The second problem area of interest is that of "work sampling" in which it is required to estimate the probability with which a worker-production system is in some well-specified condition; e.g. inoperative.

The random variable used here (denoted by $\bar{p}$ is the proportion of times, during a sample of n independent observations, that the system is observed to be in the particular condition of interest. Again, the assumption that the system is in a state of control is basic. Further, it is required that the time interval between successive observations be long enough to allow the assumption of independent observations to hold. Now $\bar{p}$ may be assumed to have a binomial distribution with a mean value, denoted by p', which represents the desired probability.

If n independent observations are made, it can be shown that an *approximate* 100 $(1-\alpha)\%$ confidence interval estimate of p' consists of a lower value

$$G_1 = \bar{p} - K_{\alpha/2}\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

and an upper value

$$G_2 = \bar{p} + K_{\alpha/2}\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

where $K_{\alpha/2}$ is defined in the same way as in Problem 1.

The number of observations required to yield a confidence interval of prescribed precision cannot be computed for this case either; similar computations as those used in Problem 1 yield

$$L = (G_2 - G_1) = 2K_{\alpha/2}\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \qquad \text{Eq. 2.}$$

Hence, L is a random variable since $\bar{p}$ is a random variable.

One method of resolving this difficulty is used when some *a priori* knowledge about the system is available and a good guess can be made for the value of $\bar{p}$. Then, as a function of the accuracy of the guess, a value of n, computed from Eq. 2., will result in a confidence interval close to or far from the required length.

A more conservative, but less frequently used method, avoids the requirement of guessing by noting that Eq. 2. takes its maximum value when $\bar{p} = \frac{1}{2}$. Hence, after a simple manipulation, n may be computed according to

$$n = \left[\frac{K_{\alpha/2}^2}{L_0^2}\right] \qquad \text{Eq. 3.}$$

and the resulting interval will always be less than or equal to L_0 for a fixed confidence coefficient $(1-\alpha)$.

A somewhat more satisfying technique which will guarantee an interval which is no larger than a pre-assigned length and which will, on the average, reduce the total number of observations is outlined. It is a double sample procedure proposed by Birnbaum and Healy (3) with the additional assumption that the distribution of the estimator used in the procedure can be approximated by a normal distribution.

It consists of the following steps:

1. Compute
$$B = \left(\frac{L_0}{2K_{\alpha/2}}\right)^2$$
2. a. Take a first sample of m independent observations, where
$$0 < m \leq \left[\frac{1}{4B}\right]$$
   b. Record $X =$ number of times that the system is in the condition of interest.
3. Compute the value of
$$Q = (1 - 2^{-(m+1)})\frac{(X+1)(m+1-X)}{B(m+1)(m+2)}$$
4. a. Take a second set of independent observations of size
$$n = [Q]$$
   b. Record $Y =$ number of times that the system is in the condition of interest during the n observations.

The confidence interval estimate is given by

$$\frac{Y}{n} \pm \frac{1}{2}L_0$$

Birnbaum and Healy also investigated the question of an optimal choice for the number of observations to be

[2] Moshman (9) describes another method of choosing a first sample size.

TABLE 1

Optimal First Sample Size (m) as a Function of p′ and B

p' \ B	.0025	.0004	.0001	.000025
.5	0	0	0	0
.4 or .6	0	0	26	47
.3 or .7	0	20	40	81
.2 or .8	11	29	59	119
0 or 1	18	48	98	198

included in the first sample; i.e. the choice of m which minimizes the total expected number of observations. They have shown that the optimal value of m is a function of p' and B (computed in Step 1). Partial results are presented in Table 1.

A value of $m = 0$ means that the single sample size given by Eq. 3. should be used; i.e., a single sample procedure is recommended.

If some knowledge concerning the approximate value of p' is available, then Table 1 may be used as a guide for the choice of m. Further, Birnbaum and Healy indicate that the expected total number of observations increases for choices of m greater than those given in the bottom row of Table 1. Hence, if no *a priori* information is available, Step 2 a. of the double sample procedure may be modified so that the first sample size is chosen so as to satisfy the relation

$$0 < m \leq \left[\frac{1}{\sqrt{B}}\right] - 2$$

(The expression on the right hand side of the above inequality gives the values in the bottom row of Table 1.)

Complete comparisons between the two methods which guarantee fixed length confidence interval estimates are not easily made. However, some partial comparisons are displayed in Table 2 in terms of the expected total sample size for a confidence coefficient of approximately .95

$$(K_{\alpha/2} = 2).$$

From Table 2, it can be seen that the double sample procedure becomes more economical than the single sample method as the confidence interval length becomes smaller, i.e. as the requirements for more precise estimates increase, and as p' decreases from .5.

TABLE 2

A Comparison of the Expected Number of Observations Used in a Single and Double Sample Procedure

	Expected Total Number of Observations	
$L_0 = 0.2$ p'	Double sample procedure with first sample size $m = \left[\frac{1}{B}\right] - 2 = 18$	Single sample procedure with sample size $n = \left[\frac{K_{\alpha/2}{}^2}{L_0{}^2}\right]$
.5	118	100
.4 or .6	115	100
.3 or .7	106	100
.2 or .8	89	100
.1 or .9	67	100
0 or 1	38	100
$L_0 = 0.05$ p'	$m = 98$	
.5	2,599	2,500
.4 or .6	2,502	2,500
.3 or .7	2,214	2,500
.2 or .8	1,734	2,500
.1 or .9	1,062	2,500
0 or 1	198	2,500
$L_0 = 0.02$ p'	$m = 198$	
.5	10,199	10,000
.4 or .6	9,806	10,000
.3 or .7	8,630	10,000
.2 or .8	6,670	10,000
.1 or .9	3,926	10,000
0 or 1	398	10,000

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An Example of Work Sampling in the Hospital*

by PAUL E. TORGERSEN

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ALTHOUGH the basic concept of work sampling was first proposed by L. H. C. Tippett (6) in 1934, it has been only in recent years that this means of work measurement has received much attention and much use. The credit for illustrating the potential of work sampling should be given to C. L. Brisley for his publication (2) in 1952 describing the basic theory of work sampling and some examples of its potential. Since that time, the utility of work sampling has received increasing recognition as evidenced by the number of recent articles (3) (5) and texts (1) (4) devoted to the theory and applications of this tool. Work sampling is now recognized as a valid and useful methodology for the measurement and analysis of work; particularly nonrepetitive work.

Perhaps the distinction should be made between the techniques of work sampling and ratio delay at this time. Both techniques rest upon the foundation of probability and inferential statistics; the use of random and instantaneous observations; and the use of the binomial distribution to estimate sample size, confidence level, and/or accuracy. Ratio delay predates work sampling however, as it was introduced in this country in 1940 by R. L. Morrow.

Ratio delay is concerned with the measurement of machine delays or down time and is an extremely accurate and useful technique in the determination of allowances for standards setting purposes. Work sampling on the other hand is more apt to be the term used to describe the analysis of human activity, although the basic theory and approach is the same. In this respect, work sampling has found many applications in the analysis of nonrepetitive work for methods improvement purposes. Thus, both techniques rest upon the same theoretical base; the distinction in nomenclature is made on application. Ratio delay is used to measure machine operations or delays and work sampling is used to measure human tasks.

The purpose of this article is to illustrate with a case study, two of the newer applications of work sampling. It is suggested that work sampling:

1. May be used to analyze human activities in a setting that might appear at first glance to be somewhat alien to the Industrial Engineer.
2. Might prove useful in measuring the performance of some professional work groups.

It is suggested that the technique of work sampling transcends the immediate and familiar industrial environment and may even be used to scrutinize some professional functions with the goal of methods improvement or task reassignment.

INTRODUCTION

The study which will be described herein was conducted through the Operations Research Group of the Ohio State University under a contract with the Division of Nursing Resources, Public Health Service, for, "The Development of a Methodology for the Evaluation of Patient Care." This study represents only one phase of the research effort and it was specifically undertaken with three objectives in mind:

1. The testing of the feasibility of work sampling as a means of measuring and analyzing work in the complex hospital world.
2. In the event the study proved successful, and it was so assumed from the beginning, it could be used to demonstrate the concept of sampling and inferential statistics to hospital administrative personnel who might not be familiar with this approach.
3. It was hoped that the above two objectives could be further reinforced by the attainment of definite and conclusive results in this specific situation.

In the first case, it was recognized that a hospital is an extremely complex organizational structure and a good deal of the work that is performed therein is of a nature that renders the more traditional methods analysis techniques unfeasible. Many hospital duties are nonrepetitive in nature and work sampling appeared to be the only economical means of obtaining accurate information about some types of work. Work sampling has proved satisfactory in the factory and there appeared to be no reason why it could not also be used in the hospital. We had as a guide, one previously reported example of work

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sampling in the hospital. Wright (7) had reported on a study conducted in a Detroit hospital although her approach was somewhat different than the one we anticipated: particularly in the choice of categories. Whereas the Wright study attempted to measure the time spent in some specific jobs, we attempted to categorize jobs using the criterion of professional versus nonprofessional work. This will be more evident when the categories of work are listed.

Due to the fact that many of the other research efforts under our contract called for the use of statistics, it was also anticipated from the onset that the work sampling study could be used to illustrate the potential of the probabilistic approach to problem solving. As an example, other studies in progress included the development of a blood bank ordering and an inventory model, a bed allocation model, etc., and it was planned to use this work sampling study to illustrate to hospital administrators, the advantages to be gained from the use of statisical models of the hospital world.

Finally, it was hoped that improvements in the work analyzed would be evident in the specific situation which was studied. Specific and concrete results would aid in the selling of this technique and remove it from the category of an academic exercise of no practical utility. These then, were the objectives of our work sampling study.

PRELIMINARY STEPS

The first step in our study was to choose a type of work for analysis. The registered nurse was selected for a number of reasons. Next to the physician, the work of the registered nurse is perhaps the most complex and diversified in the hospital world. The nurse performs a wide variety of tasks and it was realized that if her work could be analyzed, other jobs such as that of the orderly, the various technicians, etc. would be relatively simple to measure. In addition, the registered nurse is classified as a "professional" in the hospital world and the analysis of professional work would be a relatively new and challenging task. And finally, the study made by Wright included a nursing workload analysis and it would prove interesting if our results could be compared with hers even though our method of defining tasks was different. The first step after deciding upon the type of employee, was to select a hospital and obtain permission to conduct the study. In this case the Ohio State University Hospital was an ideal choice. This hospital is over 600 beds in capacity and because of its teaching and research function is probably more progressive and receptive to change than most such institutions. The Director of Nursing was contacted and gave her wholehearted support and cooperation to our plan.

The next step consisted in selecting observers for the study. Non-hospital personnel were purposely chosen in an attempt to demonstrate that an advanced working knowledge of the task to be studied is not a prerequisite of the observers in a work sampling study. If it were demonstrated that a task such as nursing could only be analyzed by another nurse or person familiar with the nursing function, this would seriously curtail the flexibility of work sampling in the hospital. Fortunately, it was found that our observers could identify and record this type of activity although a very extensive briefing on the nursing function was found to be a necessity. After the categories of work had been established, briefings were held with the observers in order that they might be able to recognize and correctly identify the many and varied functions performed by the registered nurse. Many examples of nursing activities were given and discussed during these briefing sessions.

The final step, except for the selecting of the categories of work, consisted in choosing a time and a specific place for the study. It was decided to run the study for one continuous week and include the first and second shifts (7 A.M. to 3 P.M. and 3 P.M. to 11 P.M.) only, as these shifts seemed to be the periods when the nurses were overworked. For reasons which will be evident later, two wards or stations were chosen—a clinical ward and a private ward—and data were collected separately for these two wards.

THE CATEGORIES OF WORK

The most difficult preparatory step consisted in dividing the nursing function into meaningful categories for data collection and tabulation. Due to the fact that the nurse performs an almost infinite variety of tasks, it was not thought advisable to break the work down into some specific jobs such as had been done in the study by Wright. Rather, the work was categorized into what we hoped at the time to be similar types of duties. The cooperation and suggestions of the Director of Nursing proved invaluable at this point. Many modifications and refinements were made until the final list was agreed upon.

It was assumed that anything that a nurse did would be included in one and only one of the following ten categories and extreme care was taken in defining them in order that this would hold true. The central theme in the establishment of the categories was separation of the professional duties of the nurse from other nonprofessional work which could and *should* be performed by supporting personnel, i.e., nurse's aides, orderlies, student nurses, and housekeeping personnel. The ten categories are listed as follows:

Category I. The administering to the patient of medications and/or treatments and/or other professional work, e.g., giving medicine, assisting doctor, changing bandages, etc.

Category II. Other patient contact time of a nonprofessional nature, e.g., making bed, taking temperature, feeding patient, etc. Categories I and II include all time the nurse spends in contact with the patient. The distinction between the categories is made on the basis of whether or not the work so performed could be accomplished by someone other than the nurse. To assist the

TABLE 1

The Tabulated Data

	Category of Work	Private Station		Clinical Station		Total		
		Number of Observations	Percent Occurrence	Number of Observations	Percent Occurrence	Number of Observations	Percent Occurrence	
I	*Professional contact with patient*	67	8.1%	74	9.5%	141	8.7%	
II	*Nonprofessional contact with patient*	120	14.4%	97	12.5%	217	13.5%	
	Total time in contact with the patient (I and II)	187	22.5%	171	22.0%	358		22.2%
III	*Professional preparation and conclusion to (I) above*	92	11.0%	100	12.9%	192	11.9%	
	Total professional care time (I and III)	159	19.1%	174	22.4%	333		20.6%
IV	*Nonprofessional preparation and conclusion to (II) above*	38	4.6%	29	3.7%	67	4.2%	
	Total nonprofessional care time (II and IV)	158	19.0%	126	16.2%	284		17.7%
V	*Other travel time*	24	2.8%	24	3.1%	48	3.0%	
VI	*Exchange of information about the patient*	348	41.9%	281	36.2%	629	39.1%	
VII	*Personnel Work*	47	5.6%	78	10.0%	125	7.8%	
VIII	*Housekeeping—nonprofessional*	5	0.6%	11	1.4%	16	1.0%	
IX	*Teaching*	14	1.7%	19	2.4%	33	2.0%	
X	*Idle times and meal times*	77	9.3%	65	8.3%	142	8.8%	
	Total	832	100%	778	100%	1610		100%

observers in differentiating between the two, a detailed list of all activities which should be performed by supporting personnel was provided. In order to grasp the complexity of this breakdown, it should be made known that if a patient's condition is classified as "criticial," many of the duties which supporting personnel ordinarily perform, must now be performed by the registered nurse.

Category III. Preparation and conclusion to I (professional), e.g., preparing medication, obtaining bandages, etc.

Category IV. Preparation and conclusion to II (nonprofessional), e.g., obtaining thermometer, obtaining bed linen, etc. These two categories include work performed when the nurse is not in the room of the patient and are only separated from I and II respectively in order to obtain an index of "direct patient contact" time. As an example, the preparation of a medication would be classified as Category III while the actual administration of the medication (contact with the patient) would be Category I.

Category V. Any travel time not included in III or IV.

This category was included as a "catchall" and fortunately for analysis purposes, it did not occur too often.

Category VI. Exchange of information about the patient (professional).

This category was established to measure the amount of time devoted to nursing communication of all types. It includes the oral briefing of other personnel on the condition of a patient as well as all records work such as posting medications, etc. on the patient's records, and reviewing or receiving information from the patient's records.

Category VII. Personnel work (professional).

This category includes all personnel work which must be performed by the nurse. It would be used to classify staff meetings, scheduling of patients, training received, etc.

Category VIII. Housekeeping (nonprofessional).

The category of housekeeping was established to measure work performed by the nurse that should be performed by housekeeping personnel. Again, a list of specific duties was given the observers.

Category IX. Teaching (professional).

This category was included to measure the time spent by nurses in teaching other personnel such as nursing aides and student nurses. This category was used if the nurse was demonstrating a nonprofessional task. If the nurse were demonstrating and at the same time administering a medication as an example, Category I would have been recorded.

Category X. Personal and idle time.

This category included all idle time as well as meals and coffee breaks, etc. No attempt was made to distinguish between idle time and meal time.

MAKING THE OBSERVATIONS

Approximately 1600 observations were made and recorded on a form which was provided. Room was left at the bottom of the form to make notes on any particular event which seemed difficult to categorize. As a result of the thoroughness of the briefings held prior to the actual study, a surprisingly small amount of confusion resulted. A few marginal situations arose and these were promptly explained in detail and subsequently categorized.

DISCUSSION OF RESULTS

The first and most obvious conclusion which can be drawn from these data is that the registered nurse, either by choice or by necessity, performs too much unprofessional work or work that could and should be performed by auxiliary personnel. (See Table 1.) Almost 20% of the nursing work load (Categories II, IV and VIII) consists of nonprofessional work. This breakdown was anticipated by the Director of Nursing Personnel and the study supported her contention that stricter adherence to the job descriptions of all station personnel would reduce the present overloading of the nurse.

The second and completely unexpected finding of the study was the extremely large amount of time devoted to patient communication (Category VI). On both wards, over one-third of the nurse's day is spent in patient records keeping and verbal briefings on patients' conditions. It is unfortunate that this was not anticipated and the category further subdivided into some of the facets of communication such as records keeping versus oral exchange, etc. From a methods analysis or work simplification point of view, this category of communication appears to hold the most promise for improvement. The al-

location of times to the other categories was as expected. Nursing idle time was extremely low considering that Category X includes meal time. One further and interesting fact came out of the results. It should be noted that patient contact time (Categories I and II) was approximately the same on both the clinical (22.0%) and private (22.5%) wards. However, notice that the nonprofessional contact time was 14.4% on the private ward and a somewhat lesser 12.5% on the clinical ward. This might be expected as the private patients are the "cash customers" of the hospital. And with respect to the professional contact time, the clinical ward is higher (9.5% vs. 8.1%). This substantiates a general hypothesis of the hospital world that clinical patients reach the hospital in a "sicker" condition and hence require more care, e.g., medications. These percentages are only statistically different ($P_1 \neq P_2$) at an α of some .30, but the study was not conducted to measure such differences as almost four times as many observations would have been necessary to statistically detect ($\alpha = .05$) a similar difference in proportions. However, if we stated as our hypothesis that total professional care (Categories I and III) takes more of the nurse's time on the clinical station (22.4%) than on the private station (19.1%) we have statistical difference at an α of .05.

CONCLUSIONS

A specific conclusion resulting from this study was that work sampling may be used successfully to measure work, such as nursing, in the hospital world. A prerequisite to such a study however, is assistance of some kind in defining the categories of observation and then a thorough briefing of observers on these categories. This particular study was successful in meeting our objectives; it did work, and it did serve to illustrate the concept of inferential statistics. Finally, the identification of the nonprofessional work performed by the nurse and the greater clinical ward professional care illustrations, served in a sense as an indication or check of the accuracy of work sampling with the preconceived hospital notions on these points. The realization that nursing communication consumed as much time as indicated in the results, suggests this particular item is an opportunity for methods analysis. This last point, the identification of a situation that was not fully understood by hospital administrators, helped to provide the necessary reinforcement needed, to sell the technique of work sampling.

The more general conclusions which one may reach as a result of this work is that work sampling may be useful in areas other than the traditional industrial work place, and that work sampling can be used to measure certain types of professional activity.

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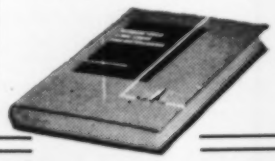

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A Planned Transition to Mechanized Inventory Control

by **RUDDELL REED, JR.**

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WITH the expanded use of punched card and integrated data processing equipment for maintenance of inventory records the problem which continually arises is how to make the transition from a manual system to an integrated data system. An abrupt changeover is generally not desirable because of the difficulty in training personnel in the new procedures and obtaining required levels of efficiency. It is necessary to retain some of the safeguards of a manual system while planning a program to reach the desired operation with as little loss in accuracy and efficiency during the changeover as possible. If convertible manual procedures are established and personnel trained in maintaining data, the conversion to mechanized data processing is accomplished with minimum difficulty. A convertible system has the additional advantage of permitting a trial of the system under operating conditions before the final installation of expensive processing equipment. Also it permits the maintenance of records under both systems during transition.

The following describes an interim procedure which may be operated manually, with punched cards only, or as part of an integrated data processing system. The system may be used independently of integrated data processing or extended to any point in the system where mechanical or electronic processing may take over.

In inventory records the data most commonly required are those concerning:

1. Materials on hand
2. Material allocated to specific jobs
3. Material available for allocation
4. Material on order
5. Cost

With the foregoing data usage rates, order points, order size, and inventory turnover are readily available. The problem is to maintain the data in such a manner that orders, receipts, allocations, and issues can be readily recorded and information for analyses or reports collected without difficulty. This demands a convenient method for standardizing recording and processing.

Standardization for manual and/or electronic maintenance may be accomplished through the use of a series of IBM-type cards, color coded for ease in manual operations, and for rapid reference under any system. Color coding permits rapid visual study of the inventory file for preliminary evaluations without the necessity for detailed mathematical or machine analysis. This is a valuable supervisory and management advantage available at little added expense with color coding.

The following procedure is an example of a convertible system and is applicable when inventory records and storeroom are physically separated. It provides for location and inventory checks within the storeroom as well as procedural checks in the operational process, thereby permitting early determination of stock balance variations.

ORDERING FOR STOCK

When an order for new material is placed, the order clerk prepares *two* open-order (pink) cards including the following information:

1. Date
2. Order number
3. Part number
4. Quantity
5. Scheduled delivery dates
6. Unit price
7. Total cost of order

One of these cards is forwarded to the storeroom to be maintained in the Open-Order file there. The second copy is filed in the Inventory-Control Status file.

RECEIPT OF GOODS

Upon receipt of the goods the storeroom:

1. Pulls the open-order card and reduces the open-order quantity by the receipt quantity.

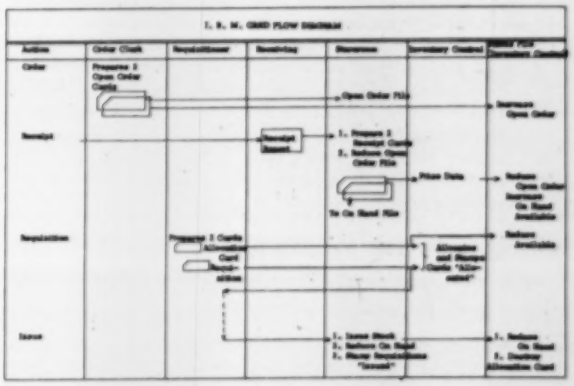

FIG. 1

2. Prepares *two* receipt cards (yellow) indicating:
   a. Date
   b. Order number
   c. Receiver number
   d. Quantity received
   e. Storeroom location
3. Files one copy in the storeroom *On Hand* file. The receipt card then becomes an On Hand record card.
4. Forwards the second copy to Inventory Control.
5. If the receipt completes the order, the open-order card is marked "complete," and forwarded with the receiver to Inventory Control for checking against their records.

Inventory Control upon receipt of the receipt card will:

1. Complete price information on the card.
2. Reduce *On Order* quantity on the open-order (pink) card and file the receipt card behind the corresponding open-order card. When more than one receipt card is involved in completing an order, they are filed by date.
3. When an open-order card marked "complete" is received from the storeroom, it is verified against the Inventory-Control file. If a discrepancy exists it is checked immediately. When the delivery is confirmed as complete, the open-order card is stamped complete and refiled in the status file.

REQUISITIONING STOCK

When material is required for a specific job the requisitioner prepares two cards, one light blue (allocation) and one black striped (requisition), giving the following information:

1. Part number
2. Quantity required
3. Date
4. Production order number for which the material is to be used

These two cards are then presented to Inventory Control for allocation. Upon the receipt of the cards, Inventory Control:

1. Files the allocation card (light blue) behind the earliest date on-hand card or cards satisfying the required quantity.
   a. If the quantity available on the last on-hand card exceeds the amount required to satisfy the allocation, the on-hand quantity is reduced by the amount used to satisfy the allocation.
2. If material is available for allocation the black-striped card is marked "allocated" and returned to the requisitioner for use in withdrawing stock from the storeroom.
   a. If material is not available for allocation, Inventory Control returns both cards to the requisitioner unallocated with information indicating the stock status. The requisitioner then is responsible for reordering, substituting or transferring previously allocated stock. (When the responsibility for stock maintenance rests with the inventory clerk, the clerk reviews the order status and initiates expediting or reorder as required.)

ISSUING FROM THE STOREROOM

Upon presentation of the allocated requisition (black-striped card) for issue the storeroom:

1. Checks its location file for the oldest stock.
2. Removes earliest On Hand cards satisfying requisition quantities.
   a. If a portion of one receipt is required to complete the requisition the quantity of the On Hand (yellow) card will be reduced by the quantity utilized.
3. Issues requisitioned stock.
4. Marks requisition "Issued" and enters on it the date of issue.
5. Forwards the requisition and any On Hand (yellow) cards which were fully utilized to Inventory Control.

Inventory Control upon receipt of the issued requisition:

1. Punches issued date into card.
2. Files card immediately behind allocation card which is identical, and destroys the allocation card.
3. Screens any storeroom On Hand (yellow) cards received against inventory control files for possible discrepancies.

Upon the publication of periodic stock status reports all records closed by filing of issued requisitions are removed from the active inventory control files and filed by part number in permanent record files for future reference as required.

After the installation of the procedure described, or one similar to it, detailed plans and schedules for integration of machine systems may be developed. The specific reports initially prepared will be dependent upon company requirements and the period necessary to attain acceptable and consistent accuracy in operation. It is usually preferable to include at first only on-order and on-hand data machine reports, incorporating allocation and availability data as the earlier runs have been refined and problems eliminated.

CONCLUSIONS

If an attempt is made to include complete transfer to mechanized systems initially, difficulties arise both in data maintenance and personnel acceptance areas. Inventory records are active work records and accuracy is paramount. By initial changeover in the areas of on-hand and on-order reports only, bugs in these areas are eliminated early, and printed records cross checked against data which continue to be maintained in manual records. When these initial reports are refined, allocation and availability data may be incorporated into printed reports and refined before eliminating the manual system.

Another advantage in using a stepped program is the added confidence personnel will develop in the machine data. As bugs are eliminated from the system, it will become apparent in comparing machine and manual records that machine record accuracy is better than that maintained in the manual system. This overcomes much of the personnel resistance (due to form data presentation) in any change.

A transitional system permits retention of desired portions of the manual system until conversion to the desired mechanized system has been accomplished. The ability to make this transition without going through a period during which inventory data is somewhat less reliable than desired, is of great importance. The use of the three card requisition system permits this smooth transition without interrupting the efficiency of operations.

Predetermined Learning Curves for Clerical Operations

by **M. D. KILBRIDGE**

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THIS paper reports on a recent effort to establish a system for predicting learning time on routine clerical operations. An experiment was performed in the clerical department of a mail order house to determine the form of the learning curves and a system was then devised for predetermining from job content the parameters of these curves.

The effort resulted in a point evaluation system for these clerical operations and a conversion table from which the parameters of the learning curves can be determined once the operation has been evaluated. The experiment showed these curves to be power functions. Their slopes fall into three groups which seem to depend on the type of office machine used, and there is a definite association between total learning time and operator effectiveness after forty hours on the job. Although the specific values developed in the investigation apply to certain repetitive clerical operations found in a mail order house, the basic principles could be applied to other types of similar clerical operations to predetermine learning curves with acceptable accuracy.

LEARNING CURVES AND LEARNING TIME

Learning curves show worker productivity as a function of learning time (1) (4) (5). When operator effectiveness, or per cent of standard, is plotted against learning hours, the time required for learning a task and the rate of progress at various stages can be clearly seen.

Learning curves are frequently used in industry for assistance in:

1. Evaluating the progress of new employees by comparing their performance with a standard learning curve (3).
2. Predicting early in the learning process whether a new employee will be able to reach standard performance.
3. Determining the effectiveness of the training program.
4. Advising new employees of their progress as compared to expectancy.
5. Determining "learner's allowance" for purposes of wage incentives.
6. Establishing the standard cost of employee training and the expense of employee turnover on different jobs.
7. Aiding in the use of manning tables and replacement schedules.

In the construction of learning curves two things are important: the form of the curve and the total learning time required to reach standard performance. In most industrial situations this information is obtained by keeping the production records of several employees and averaging the time required for them to reach standard performance. An arbitrary learning curve is then drawn, frequently in a rough "S" form showing something of a plateau at about the midpont of the curve. The system is simply to connect the point of initial productivity upon starting the task with the point of 100% productivity by a "typical" curve. Although this method for constructing learning curves is widely used today, it has obvious deficiencies.

Considering their broad usefulness and potential as tools of cost reduction, it would seem that a more effective and systematic approach could be used to determine learning curves. What is required is a logical method of predicting both the learning time and the form of the learning curve on the basis of the nature and content of the operation. If a valid and reliable system for predetermining learning curves were available, operator performance could be compared to this standard from the start, with some confidence that the results were meaningful (6). This paper shows how such a system was established for routine clerical operations.

The learning time referred to in this investigation is on-the-job learning time. It does not include a formal training period, sometimes referred to as "vestibule training" or "initial training." Such training is customarily conducted by an instructor in a special training area prior to the operator's being sent to the operating department. During this vestibule training period the new operator practices performing the job with dummy material. Only when she is able to perform the operation with acceptable quality, is she transferred to the department in which the job is done and her "on-the-job learning" begins. On-the-job learning extends from the time the employee is transferred to the working department until she produces consistently at 100% of the production standard. This is the "learning time" referred to in this paper.

PROCEDURE FOLLOWED

The investigation was conducted in a clerical department of a mail order house. Eight repetitive clerical operations, representing a cross-section of clerical work in

the organization, were chosen for analysis. The production records of new workers were kept, converted to percent of standard, and plotted against learning hours. This was continued until most of the workers in the test group had reached standard. Smooth curves were then fitted to the resulting families of curves. At this stage the form of the learning curves was known. The selected jobs were then analyzed in conjunction with these average empirical curves to hypothesize on the factors influencing learning time. Next these factors were plotted against learning time to study possible correlations. When the factors thought to influence learning time were decided upon they were compared for relative importance and an absolute weight assigned to each. The factors were then broken down into degrees and point values assigned to each degree. The test operations were then evaluated with this point system and the results proved to be consistent. The point scale was then verified by repeating the above test procedure for three other repetitive clerical operations.

SELECTING THE OPERATIONS

The operations were chosen so as to meet the following list of specifications:

1. Operations must be of a repetitive clerical nature.
2. A production standard established by time study or micromotion analysis must be in effect.
3. Operations must be covered by the wage incentive plan with a history of reasonable bonus payment.
4. The job method and physical facilities must be good and no changes can be pending.
5. There should be at least three operators performing the work.
6. There must be no interference with pace or production because of schedule limitations or lack of work.
7. Operations must differ from each other in at least two of the following aspects:

a. Length of cycle (wide range desired).
b. Use of machinery or equipment.
c. General complexity.
d. Skill or dexterity required.
e. Analysis or judgment involved.
f. Knowledge of methods, procedures, media, or materials.
g. Physical effort.

Of the many operations performed in this department, only eight could be found which satisfied these conditions. They ranged from simple hand stamping of mail orders to the operation of automatic National Cash Register machines to distribute charges and credits into various accounts. The standard output requirements in terms of units produced were very high, ranging from 350 units per hour for the slowest operation to about 3,700 units per hour for the fastest operation. The following is a summary of the operations.

Operation 1. "Separate pouch from cash orders"
Machine used: None.
Required hourly output: 1000 units.
Purpose: To determine that cash orders have been completely handled, and to remove order pouch from orders, order backs, and envelopes.

Operation 2. "Single order stamping and sorting"
Machine used: None
Required hourly output: 629 units.
Purpose: To hand stamp with date and schedule numbers, and to sort all single-item orders for parcel post and metropolitan delivery.

Operation 3. "Sales slip sorting (seated)"
Machine used: None.
Required hourly output: 3670 units.
Purpose: To sort sales slips by first digit of merchandise department number.

Operation 4. "Order sorting (standing)"
Machine used: None.
Required hourly output: 1754 units.
Purpose: To sort cash and credit orders by state into 49 locations in a sorting rack.

Operation 5. "Sales listing"
Machine used: Clary adding machine (full key board—fast operating)
Required hourly output: 2000 units.
Purpose: To list from sales slips the total dollar sales by merchandise department.

Operation 6. "Machine stamping"
Machine used: Standard addressograph machine
Required hourly output: 351 units.
Purpose: To stamp orders and corresponding sales slips with schedule numbers.

Operation 7. "Order distribution"
Machine used: Automatic National Cash Register
Required hourly output: 1614 units.
Purpose: To operate a N.C.R. distributing machine to distribute charges and credits into various accounts from credit orders, and to obtain totals of accounts so that totals may be checked against one another for balancing purposes.

Operation 8. "Memo and R-card distribution"
Machine used: Automatic National Cash Register
Required hourly output: 1205 units.
Purpose: To operate a N.C.R. distributing machine to distribute charges and credits into various accounts from information contained on memoranda and returned goods notices, and to obtain totals of accounts so that totals may be checked against one another for balancing purposes.

SELECTING THE EMPLOYEES

Actually, the employees of the test group were preselected as a homogeneous and representative sample by the company's employment practice which involves the use of two pre-employment tests, the Minnesota Clerical Test and the SRA Verbal Form. Job applicants are assigned to work of varying difficulty based on their test scores. The classification of new employees by test scores and their assignment to a corresponding grade of work is done routinely following an "assignment scale" which correlates test scores with job grades. The test group whose performance was studied in this experiment was thus thought to be rather homogeneous and typical with respect to the relevant characteristics to be tested by the experiment and similar to future groups to which the results of the experiment would be applied.

A further requirement considered in selecting members of the test group was that they must be new employees in the company. Persons transferred from other departments or other jobs were not included. Since the operations chosen for study were peculiar to the company, it was felt that transfer of training from outside the company was

negligible. The only exception to this was in the use of certain office machines. Aside from these criteria no other considerations were involved in the selection of the test group. All the operators were women. They were married and single, and ranged in age from 18 to 52. Although these women constituted a test group, they were unaware of the fact. A total of 75 employees were included in the original test group. Of these, 52 completed the learning period and reached standard performance and 23 were separated from the payroll before reaching standard. The 52 who completed the learning period became a stable, effective work force.

PRODUCTION STANDARDS

A wage incentive plan is in use in the company which associates pay with production on a current and continuous basis. It is a standard-hour plan with a single wage rate for each job evaluation grade. The single standard wage rate is the basis of bonus calculations. Standard hours produced are multiplied by the employee's standard wage rate to determine standard earnings. Bonus is paid for production above standard on a one-to-one ratio in direct proportion to increased output. There is no ceiling on earnings except the ability of the worker to earn them. If an incentive employee should earn, for any one pay period, an amount that averages less per hour than her guaranteed hourly rate, she is paid the guaranteed hourly rate for the total hours worked. Incentive earnings for all employees are computed on a weekly basis.

Incentive standards are set in such a way that an average qualified operator, working under good operating conditions, without restrictions or limitations, and making full use of her skill and work capacity, can, on the average, exceed the standard requirements by approximately 30%. Regardless of the amount of bonus earned, production standards are guaranteed against revision as long as the operation is not changed. Adequate allowances are included in the standard to compensate for loss of production due to the effects of fatigue, personal needs, and other factors.

In order to make full use of the data acquired from the eight test operations, and to generalize from the results obtained, it was necessary to make some assumptions. First, it was assumed that the production standards on the eight operations studied were reasonable requirements of output per hour, and that they were consistently requiring, that is, that some were not "tight" and others "loose." Since the time required to reach standard depends largely upon what the standard is, this assumption is perhaps the most important underlying the experiment. Second, it was assumed that the working methods upon which the production standards were based were satisfactory and involved smooth and efficient motion patterns. Third, it was assumed that the operators studied were trying to reach standard performance and were not holding back, or extending the learning process, either intentionally or unintentionally. And, fourth, it was assumed that work was always available in sufficient quantity to keep the operators working at their desired pace. Since the department involved in these studies used the "controlled backlog" (a programmed accumulation, always assuring a uniform work flow) system, a constant pressure of work was always present, justifying this assumption. Fifth, it was assumed that the operators studied were typical of employees who will be hired to work on these jobs in the future and that the behavior of this group could be used to predict the behavior of future employees. Sixth, it was assumed that there were no other influences operating which would militate against the operators trying, or being able, to reach standard performance in minimum time.

THE RESULTING CURVES

Production data for operators in the test group were taken directly from the employee's daily production record which is used to calculate production bonus and hence is a reliable source of information. From this report the department instructor transferred pertinent information about hours, production, efficiency, and quality to a learner's progress record designed for this experiment.

Learning curve points were plotted on a weekly basis at the end of the period, not in the middle of the period. Thus, after 40 learning hours the employee's production for that 40 hours was divided by the standard 40 hours production, and the resulting per cent of standard plotted as the employee's effectiveness at 40 hours. However, this is actually not the employee's effectiveness at 40 hours, but the average effectivenes during the 40 hour period. The effectiveness at 40 hours would be somewhat higher than the point plotted. The result of such practice is to slightly lower the learning curve. However, the form is retained, and the resulting apparent difference in time to reach standard performance is negligible compared to the over-all time.

All operators working on the same job were plotted on the same graph, and each operator's performance was plotted until she consistently exceeded the standard, or was separated from the payroll. Through the families of curves resulting from the above procedure a smooth curve was fitted for each operation. These curves were then transferred to a single sheet of rectangular cross-section paper. The results are shown in Figure 1.* An examination of the curves reveals that they are all of the same form and appear to be power functions. Because of the second observation it was decided to transfer the curves to log-log paper, since a true power function of the form $y = ax^b$ will produce a straight-line curve with logarithmic coordinates. Figure 2 shows the same curves on log-log paper. They are indeed straight lines, and certain dif-

* The curves were extended back to zero hours by simple extrapolation.

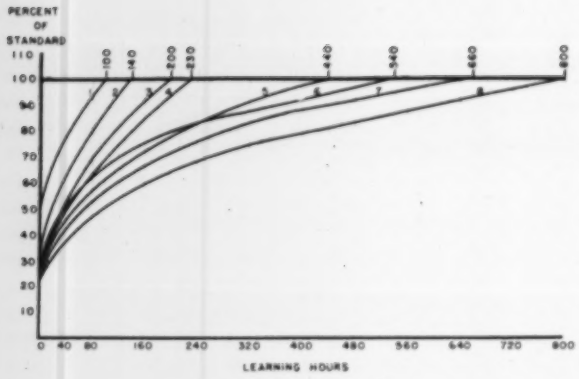

FIG. 1

ferences in slope are now apparent. Following are the equations of the 8 curves, their derivatives, and the slope of each curve at three points, at 40 learning hours, at one-half the total learning time, and at the total learning hours, or 100% of standard. The slopes at the three points seem to be grouped as follows: Curves 1, 2, 3, and 4 are similar, curve 5 is different from all others, and curves 6, 7 and 8, are similar.

Equations of The Learning Curves

Curve No.	Equation of Curve	Equation of Derivative	Slope at 40 hours	Slope at ½ Total Learning Hours	Slope at Total Learning Hours
1	$y = 26.89x^{-.29}$	$y' = 7.67x^{-.71}$	.55	.47	.28
2	$y = 16.16x^{-.37}$	$y' = 5.98x^{-.63}$	.56	.41	.26
3	$y = 12.36x^{-.39}$	$y' = 4.82x^{-.61}$	.53	.30	.20
4	$y = 8.06x^{-.48}$	$y' = 3.87x^{-.52}$	.58	.34	.24
5	$y = 13.94x^{-.32}$	$y' = 4.52x^{-.68}$	.47	.12	.073
6	$y = 18.73x^{-.27}$	$y' = 5.04x^{-.73}$	.34	.083	.050
7	$y = 14.16x^{-.30}$	$y' = 4.25x^{-.70}$	.32	.074	.046
8	$y = 10.88x^{-.33}$	$y' = 3.59x^{-.67}$	.31	.061	.041

An analysis of the slopes shows a definite grouping throughout the length of the curves. Curves 1, 2, 3, and 4 have an average slope at 40 hours of .56, with a standard deviation of only .05. Curve 5 has a slope of .47 at 40 hours. Curves 6, 7 and 8 are grouped around an average slope of .32 at 40 hours, with a standard deviation of only .03.

The only hypothesis suggested for this grouping of slopes related to the type of office machine used. Thus, operations 1, 2, 3 and 4 involve no machine while operation 5 is performed on a full-keyboard adding machine. Operation 6 involves an addressograph machine and operations 7 and 8 are performed on National Cash Registers. Why these machines grouped in such a way should produce learning curves of similar slope remains to be answered.

Once the grouping of operations by type of machine used became a factor in the analysis, it was discovered that within each group there was a definite relationship between the total learning time and the effectiveness, or percent of standard, at 40 hours. This relationship is extremely important. Using it one can draw the typical learning curve knowing only one thing, the total learning time. This is true because of the straight-line nature of the learning curves on log-log paper. Only two points are required to draw a straight line, and if one point, the hours to reach standard is known, the second point can be found from the above relationship. Thus, if a system could be devised for predicting learning time on the basis of job content, with the above relationship the expected learning curve could also be predicted.

FACTORS AND THE POINT SYSTEM

By studying the learning curves resulting from the 8 test operations and comparing the job content with the total learning time, it was possible to hypothesize on the factors which might influence learning time. (These factors had been guessed at in the beginning when the operations were chosen and, in fact, influenced the criteria for selection.) The six factors assumed were:

1. Skill and dexterity
2. Knowledge of methods, procedures, media or materials
3. Analysis and judgment
4. General complexity
5. Use of office machine or equipment
6. Length of cycle

Most of these factors, except 6, would probably be found in any point job evaluation plan for office work. Factor 6, length of cycle, was added for this reason: operations of short duration are repeated more frequently in a given period of learning time than those of longer duration and more frequent repetition will naturally accelerate the formation of habit patterns. Consequently, learning time should increase with an increase in length of cycle. There are implicit assumptions involved in the selection of these factors which are extremely difficult to explain. However, at this stage, their selection constituted an hypothesis only.

To test these factors and get some idea of their comparative weights, four persons with detailed knowledge of the test operations were asked to rank these operations by factors. The rankings were then correlated with actual average learning hours with a resulting coefficient of correlation of .85. On the basis of these rankings it was de-

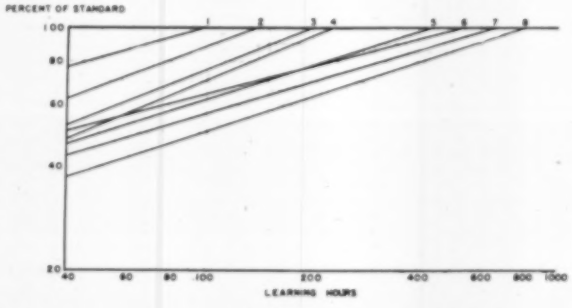

FIG. 2

cided to simplify the procedure by eliminating factor 4 and doubling the weight of factor 3, since factors 3 and 4 were ranked almost identically on all eight test operations.

It was therefore hypothesized at this point of the analysis that there are five major factors influencing learning time on routine clerical operations. A point system was then established based on these five factors. The factors were each subdivided into 6 degrees and the factors and degrees defined.

Next, points were assigned to the factor degrees. In such cases it does not matter what total number of points is used for distribution among the factors and degrees. What is important is whether the points should be allocated among the degrees in an arithmetic or geometric pattern. The difference is one of some consequence. It was felt that if an arithmetic progression were used, there might be a tendency for the line of point-hour relationship to curve, whereas a geometric progression might produce a straight line relationship (2). This situation seemed probable because an arithmetic progression might not give enough points to the very difficult jobs to set them apart properly from the very easy jobs. Figure 3 shows the resulting point system. The difinitions of degrees for factors 4 and 5 require that operations be grouped by type of machine and length of cycle. In the case of factor 4 this is actually a distinction in kind rather than degree.

After the points were allocated to degrees the same supervisors who performed the ranking on the original factors were asked to decide the degree of each factor for each job. An average was taken, the total point values of each of the eight jobs determined on this basis, and from these relationships of total points to learning hours the point-hour curve was drawn. This was done by plotting total points against total learning hours for each of the eight test operations, and then fitting a curve by least squares to the resulting scatter diagram. The result is a straight-line curve with equation,

$$\text{Learning Hours} = \frac{\text{Total Points} - 18}{.18}$$

Finally, from this equation the conversion chart of Figure 4 was made. This chart shows total learning hours and effectiveness at 40 hours as functions of the total points. Effectiveness at 40 hours depends on total points and on the type of office equipment employed. Using the values contained in this chart it is possible to draw a predicted learning curve once the total point value of the operation has been determined. The learning curve should for greatest ease be drawn on log-log paper where it will result in a straight line. Since only two points are required, one being the total learning hours and the other the per-cent of standard at 40 hours, this conversion chart provides all the information necessary to draw the learning curve.

Factors	1st Degree	2nd Degree	3rd Degree	4th Degree	5th Degree	6th Degree
1. Skill and dexterity	4	6	9	14	21	32
2. Knowledge of methods, procedures, media, or materials	4	6	9	14	21	32
3. Analysis and judgment	8	12	18	28	42	64
4. Use of office machine	4	6	9	14	21	32
5. Cycle time	4	6	9	14	21	32

FIG. 3. Point Allocation to Factors and Degrees

Total Points	Learning Hours	Effectiveness at 40 hrs. (% of std.)		
		No Machine	Adding Machine	N.C.R. or Addressograph
24– 27	45	98		
28– 31	65	89		
32– 35	85	83		
36– 39	105	76		
40– 43	125	68		
44– 47	145	62		
48– 51	165	59		
52– 55	185	55		
56– 59	210	51	*	
60– 67	250	46	67	
68– 74	290	42	61	*
75– 81	330	40	56	72
82– 89	370	37	51	68
90– 96	410	35	48	63
97–103	450	33	45	59
104–111	490	31	43	55
112–118	530	30	41	52
119–125	570	29	39	49
126–131	610	28	37	47
132–139	650	27	36	44
140–146	690	26	34	42
147–161	760	25	32	39
162–175	840	23	30	36
176–189	920	22	28	33
190–200	990	21	26	31

* Data not available above this point.

FIG. 4. Conversion Chart—Points to Hours

To recapitulate, the system is simply to determine what degree of each factor applies in the operation being studied, to total the corresponding points, and then to look up this total on the conversion chart. From the chart are read values which determine the learning curve, the total learning hours which are plotted at 100 per cent of standard, and the effectiveness, or per cent of standard, at 40 hours which is plotted at 40 hours of learning time. Through these two points a straight line is drawn which represents the standard learning curve for that operation.

VERIFICATION

To verify the point system established on the basis of eight test operations, three additional operations were chosen for study. The criteria for selection of these operations were the same as those used for the original experiment. Following is a summary of the three verification operations.

Operation V-1. "Mail opening"
Machine used: None.
Required hourly output: 135 units.

Purpose: To open, analyze, classify, and prepare incoming customer mail for further handling.

Operation V-2. "Cash analyzing"

Machine used: Adding machine.

Required hourly output: 297 units.

Purpose: To validate and total customer remittances that accompany cash orders.

Operation V-3. "Cash order remittance posting"

Machine used: National Cash Register.

Required hourly output: 1200 units.

Purpose: To read and post order amount into N.C.R. machine which stamps amount onto order.

Since all operations in the initial test department that satisfied the criteria established were used in the original experiment, it was necessary to move to another department to find operations that could be used for verification. The department chosen was immediately adjacent to the test department. The same wage incentive system was in effect in this department and the method of controlled backlog of work was also used. The only real difference between the two departments was the difference in supervision.

Twenty-six employees, chosen in the same way as the original test group, were involved in the verification group. Of these, 19 completed the learning period and reached standard performance and seven were separated from the payroll or transferred to other work.

Again, the supervisors were asked to decide upon point ratings for the work involved. The average number of total points was used to predict the learning curves ,and the predicted curves drawn by use of the conversion chart.

Actual production records were kept and the corresponding empirical learning curves drawn for the employees as they progressed through the learning process. When the 19 operators who finished the learning period had reached standard an average curve was drawn for each of the three families of curves directly on log-log paper, and, as had been expected, resulted in straight lines. A comparison was then made of the predicted with the empirical learning curves. Naturally, they were not identical, but the differences were determined and percentage-wise are reasonably small.

In comparing the average empirical curve with the predicted curve for each of the three verification operations, two points were taken from the curves in each instance and the percentage difference calculated by the relationship $\frac{|P-E|}{P}$, where P is the effectiveness, or per cent of standard, at a point on the predicted curve, and E is the effectiveness for the corresponding point on the empirical curve. For the three sets of predictions the average percent differences were 4.2%, 6.1%, and 8.9%, respectively.

The system was next tested for reliability to analyze the consistency of the ratings which result from its use. Of course, any measure of reliability will necessarily reflect the consistency of the raters as well as the consistency of the rating system. A simple analysis was made to find the relative deviation from the average for the total points assigned by each rater to all three jobs. The total points assigned by the four raters were 119, 126, 130, 112 respectively with an average of 122. The relative deviations were 2.5%, 3.3%, 6.6%, 8.3% respectively. This is considered a very acceptable error percentage for values based on judgment.

It is regretted that a proper statistical analysis of validity and reliability could not be made for the verification procedure, but the way in which the original data were handled in determining average curves and the small size of the sample made this inadvisable. Therefore, only the above rough and ready comparisons were made.

HOW THE SYSTEM WORKS

In summary, here is how the learning curve is drawn for a specific operation. First, the operation is rated by use of the point scale of Figure 3 in conjunction with the related definitions of factors and degrees. Using the resulting point total, we refer to the conversion chart of Figure 4 from which the total learning hours, that is, time to reach standard, can be read directly. This gives one point on the learning curve, the learning hours for 100% efficiency. Next, we read from the conversion chart the effectiveness at 40 learning hours which depends upon the type of office machine used. This is the percent of standard, or efficiency after 40 hours on the job and provides a second point on the curve. When these two points are plotted on log-log paper and connected by a straight line, the result is the predicted learning curve.

CONCLUSIONS

Before listing the specific conclusions resulting from this investigation, certain limitations in the design and conduct of the experiment must be re-emphasized. The entire study is based on an analysis of only eight test operations and three verification operations. Although an attempt was made to choose these operations to represent a cross section of routine clerical work in the company, this was not completely possible, and certain types of jobs, such as those involving typewriters and comptometers, were not represented.

Also, the total number of employees in the test group and verification group was fewer than might be desired. Although 101 operators were involved in all, only 71 completed the learning period. This averaged less than seven employees per operation, yet it was necessary to use the results of their performance to determine the empirical learning curves.

Also, the ranking of factors and the pointing of the test operations rest on the judgment of only four persons. It would have been difficult, however, to increase the number of persons involved in these ratings because there were no others sufficiently familiar with the work to make these judgments.

All things considered, the following tentative findings seem worthy of statement.

1. Learning curves for repetitive clerical operations show no plateaus.
2. These learning curves are power functions.
3. The slopes of the straight-line learning curves on log-log paper fall into three seperate groupings which seem to be associated with the type of office machine or equipment used.
4. There is an association between total learning time, that is, time to reach standard performance, and effectiveness at 40 learning hours.
5. It appears to be possible to predetermine, for repetitive clerical operations, the time required for average operators to reach standard performance.
6. This prediction can be made with acceptable accuracy on the basis of job content.

This system was devised specifically for predicting learning time on repetitive clerical operations in a mail order house. There is no reason, however, why it could not be used for similar work elsewhere. It may be useful, in about its present form, in other mail order houses, banks, insurance companies, government offices, and similar organizations where a mass paper flow is handled in a step by step sequence. In adapting this plan to other clerical situations it would undoubtedly be necessary to change the specific values. This would involve establishing empirical curves by charting the learning progress of typical employees on a variety of operations, and with the resulting information, revising the conversion chart.

In the final analysis the workability of this system depends upon the judgment of the evaluators. The degree of error can be reduced by having several persons evaluate each operation and using the average results, but judgment remains the controlling factor.

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*People Are Funny: Industrial Engineering and the Human Equation**

by **ELLIOTT DeFOREST**

Partner, Joseph B. Ward and Associates, Seattle

ENGINEERS of our generation function in an atmosphere of public approbation and esteem. The shortage of engineers is a matter of congressional concern. The engineering graduate gets the red carpet treatment from industry. No doubt much of this stems from the increasing technical complexity of our world—a world in which machines are the masters of so many that the layman respects those who seem to cope with the machine. The engineering approach, with its insistence on a factual foundation and a solution based on tested principles, produces finite conclusions which are vastly reassuring to the untrained. When, in addition, the subject is wrapped in an impressive but incomprehensible trade jargon, the degree of lay acceptance is often increased.

This is not to belittle the engineering approach—only the reverence of the man on the street for what to him is a mysterious procedure, and his frequent blind acceptance of some statement because "the engineer says so." Within limits, he is, of course, warranted in respecting engineering opinion on engineering matters. Our fellow engineers in the civil, mechanical, electrical, chemical and similar fields that deal with physical problems have an honorable history of problem solving through the application of accepted formulae to the case at hand. Engineers the world over are designing, building and operating more efficient machines through the use of common concepts of action and reaction—friction, hysteresis, adiabatic curves, atomic weights, catalysts and bending moments, thinking in common terms and expressing themselves in a common language of mathematics and charts and working drawings. Their success in dealing with the forces of nature has not been stopped by political boundaries, and their prestige is equally wide spread.

* Award Winner, Annual Technical Papers Contest, Seattle Chapter, AIIE.

INDUSTRIAL ENGINEERING RESPONSIBILITY

The Industrial Engineer shares in this glory by virtue of his college degree, his opportunity to practice under a professional license, and his general acceptance by and association with the fraternity of engineers. For him, however, there is an added responsibility. Many of the matters with which he is involved include factors heavily dependent upon the human element. At the same time that he is dealing with feeds and speeds, with hardness, with machine hour rates, with depreciation and other things which have been reduced to reasonably consistent tables, he must remain aware of the extreme variability in skill, in physical condition, and in mental attitude of the man who operates the machines. With scientific zeal, he does his best to reduce this great variable to workable terms. He breaks operations down into elements (therbligs) makes observations of a large number of individuals, and computes medians and averages. He pre-determines motion times on a theoretical basis and adds allowances. He studies processes and makes flow charts and eliminates waste effort and awkward motions. The danger which he faces is that through long association with the mechanical side of his work, he comes to regard the personal allowances as a mathematical correction and forgets that they stem from the man himself—his dexterity, his fatigue, his desire to do the job.

LEARNING CURVE

Industrial Engineers are familiar with the learning curve—that as a task becomes familiar through repetition, production per unit of time decreases to a point where a levelling off representing maximum capability is reached, and that this affects a whole factory, as when a new model of aircraft goes into production. During the war, we found the learning curve applying to ships, with total man hours dropping steadily from one hull to the next, except that they went up to fantastic heights with the last hull. This was the point where human desire to stay on the payroll exceeded human interest in getting a job done. To take a more recent example, a factory which is on a program of gradual reduction of work force may get lower unit costs than one which is hiring every warm body in sight.

It may seem that we are emphasizing the obvious. We do so only as a prelude to further amplification. What happens to the man in the factory also goes on in the warehouse, the sales agency and the retail store. In the factory, a variation in unit costs is immediately measurable and apparent. Elsewhere the relation between cause and effect is often difficult to relate and to evaluate.

NEED FOR GOOD MANAGEMENT

Since the publicized subject of labor disputes is nearly always the hourly wage and fringe benefit item, other causes of labor unrest may be overlooked. We recall a Canadian pulp mill where the president could not understand why he had continued grumbling and high turnover while paying the industry scale. A scientifically conducted survey revealed that pay was not a primary concern—71 per cent of the employees thought they were being paid a reasonable rate, although 53 percent were unhappy about the way pay matters were handled. Of much more concern to them was the inconsistency of the management in making decisions, its failure to instruct employees thoroughly about their jobs, its lack of attention to safety conditions, too much driving by some supervisors and not enough by others. Half of the employees felt that everybody was trying to boss them around, and that there was no real employment policy. Here was a well-engineered plant in a turmoil because of failure to realize that its men wanted a sense of direction and a feeling of understanding by and confidence in the management.

Tact and understanding can remedy many technical errors. Every Industrial Engineer knows that a man cannot serve two bosses—the books say so, and there are plenty of examples to prove that the books are right. In a certain hospital, an experienced administrator resigned. The Executive Board promoted the former office manager as successor, but having some doubts about his knowledge of medical problems of a hospital, made him subject to supervision by the Medical Staff as well as by the Executive Board. This was a multiplicity of bosses and division of responsibility to a high degree. Because the new man was both able and tactful, he made this unwieldy situation work and had no difficulty with his many bosses. The book is still right, but the human element overcame the technical difficulties.

TECHNICAL PERFECTION

The engineer can lose sight of reality in striving for technical perfection. A certain county wanted a comprehensive plan of development, and engaged a consultant from "the big city" to do the job. Following accepted practice, this consultant made a thorough survey of land uses throughout the county as a basis for further planning, and presented the county with a bill for $30,000. The commissioners nearly dropped dead from the shock, and cancelled all further planning efforts, although the need for them was recognized. Here is a case of a "big time operator" failing to lower his sights to the human element of ability to pay. Granted that land use information is a prerequisite to planning, were there not other less costly methods of securing adequate information than a costly section-by-section coverage of the entire county?

For the average manufacturer, the concepts of time and motion study are often unrealistic, but, work sampling may serve his purpose as well or in some cases even better. The concept of electronic data processing is beyond his understanding and financially out of his reach. For instance, with today's costs, it is estimated that only 34 of the 6,000 savings and loan associations in the United

States can profitably use electronic computers. The engineering consultant, as an outside adviser, may find the way to bring the benefits of the electronic age to a greater number, perhaps through joint use of a tabulating service. In many businesses, a full time Industrial Engineer will not be hired as such, but one who can do purchasing, act as personnel manager and perhaps as corporation treasurer may be accepted by management, and surprise his employer by utilizing engineering practices in many fields not commonly thought of as Industrial Engineering opportunities. The point is that the Industrial Engineer who seeks the perfect job and who narrows his outlook also narrows his service potential and his job openings.

HUMAN ENGINEERING

Human engineering is not something often taught in engineering schools. Their curricula must contain a large proportion of courses with specific engineering content. They are obligated to teach basic principles thoroughly, because their engineering degrees imply such knowledge, and employers and graduate schools expect it. The same complexity of the modern world which creates added respect and opportunities for the engineer complicates the problem of the technical school. N. N. Barish, talking about a proposed *broadening* of the curriculum of the Industrial and Management Engineering Department of New York University suggests a ratio of approximately 70 percent of the hours in technical subjects and 30 percent in human behavioral sciences and general studies (1). Study of other colleges reveals that this is indeed a liberal proposal. They are hard put to cover in four years the essentials of any branch of engineering without allotting time to psychology, English, literature, political science, economic analysis, corporation finance, business law, etc. The university cannot "teach" experience or judgment, nor is it likely, except in an extra curricular manner, to provide much education in the art of getting along with people. The burden is still on the practicing Industrial Engineer, as it is on any professional man, to keep on with his studies, both of technical advances in his field, and of the relation of his work to the whole picture. It is his obligation to recognize the human variables which enter into the application of text book principles, and to see the whole forest—not just the trees.

CONCLUSIONS

It is a proper function of the American Institute of Industrial Engineers, or any of its chapters, to keep alive this awareness. The fascination of technological improvement is a constant allure. A study of three recent volumes of the *Journal of Industrial Engineering* reveals the following breakdown—technical articles—67 percent, articles on the humanities and on the profession of Industrial Engineering—33 percent. I am sure that most chapter programs would follow the same pattern. My thesis is that the programs and proceedings of a chapter should encompass not only technical subjects, and the application of Industrial Engineering techniques to specific problems, but also the importance of considering people—customers, clients, employees, supervisors—not as identical parallel marks on a chart, but as human beings with varying aspirations and reactions to a living environment.

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An Investigation of Some Factors Affecting the Hand Quality Picking of Small Objects

by **JOSEPH J. MODER**

Professor, School of Industrial Engineering, Georgia Institute of Technology

and **JESSE H. OSWALT***

School of Industrial Engineering, Georgia Institute of Technology

THERE are a number of industries that use hand picking as a method of removing defective items from their product. Although examples of this operation can be found in the metal and plastics industries, it is more prevalent in the food processing industry where beans, nuts, coffee, citrus fruit, and other commodities are routinely processed in this manner. The scope of this operation is suggested by the peanut industry which spends in excess of one million dollars annually on this operation. With the latter industry in mind, a research project was conducted at the Georgia Institute of Technology which consisted of separate thesis reports by Calhoun (1), Zimmer (9), Wright (8), and Olivares (7). Certain of the results of these tests, which are applicable to the more general problem of quality picking or sorting small objects, are presented below. These results indicate that a ten percent reduction in the cost of this operation is possible in the peanut industry.

The operation of hand quality picking can be described as follows: the objects to be picked, or sorted, are presented to the operator's view on a horizontal moving belt; as the objects move within the operator's reach, the defective units are picked out and placed aside.

An extensive study of a closely allied operation was made by Malcolm and DeGarmo (5). This was a study of the grading operations encountered in the processing for market of citrus fruits, potatoes, etc. Malcolm and DeGarmo raised a valid objection as to why motion and time study techniques could not treat this problem adequately, which justified the empirical approach to this general problem. The objection raised was that the defective objects are presented randomly spaced in a haphazard fashion and the visual-reaction-decision time on the part of the operator would be difficult to measure.

The operator's visual impression and reaction time is important because it is an appreciable part of the total picking cycle time, and further, it fixes the maximum picking rate for each operator which normally may not be exceeded. Tests have shown that the shortest time possible for a person to see an object and to get an adequate visual impression of it ranges from 0.07 to 0.30 seconds, the average being 0.17 seconds (4).

Illumination of the workplace is another factor which studies in the literature have shown will affect the picking operation in three ways:

1. An insufficient amount of light for adequate contrast of objects will cause operator fatigue.
2. The intensity of illumination will affect the visual impression time.
3. The quality of the finished product will be affected.

For best results in an inspection operation, Marks recommends an illumination level of 30 to 100 foot candles (6).

OBJECTIVE OF THE STUDY

The objective of these tests was to study the effects of the following factors on the net picking rate—i.e. rate of removal of damaged units and the percent of good objects in the pickouts.

1. Operators
2. Picking method
3. Picking position
4. Belt speed
5. Damage content
6. Density of objects on the belt
7. Total rate of flow of objects
8. Operator learning

The experimental designs used to investigate these variables were all of the mixed model factorial type, i.e. they all contained a combination of r ndom type variables such as operators, as well as fixed type variables such as picking method, position, etc. A detailed example of only one of these experiments is given in the Appendix.

APPARATUS AND TEST CONDITIONS

An endless green belt 12 inches wide, made from two-ply plastic coated cotton, was used for conveying the objects to be subjected to hand quality picking. The

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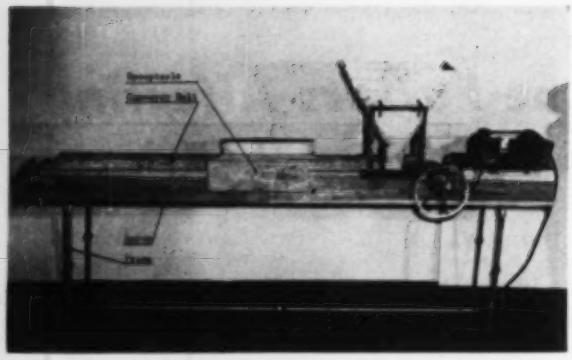

FIG. 1

equipment, shown in Figure 1, provided for both the adjustment of the feed rate of the objects to be picked, and the speed of the belt. The height of the work surface was fixed at a level of approximately three inches below the operator's elbow, and the lighting intensity was held at an average level of 70 foot candles, as recommended in the literature cited.

Great Northern beans were used as the objects to be picked and Pinto beans were used to represent the damaged or defective objects. Both of these types of beans are about the same size. However, the Great Northern beans are white, while the Pinto beans are speckled brown. These types of beans were selected because of their size, their resistance to wear, and their sharp contrast in appearance. This latter factor had the desirable effect of virtually eliminating the need for training the test operators in the recognition of a defective object.

Calhoun's portion of the test was conducted in a food processing plant in Atlanta, Georgia, which employed female operators. The remainder of the tests were conducted on the campus of the Georgia Institute of Technology and used male students as the operators. The conditions of the tests were such that the temperature and humidity were of a comfortable nature at all times.

DISCUSSION OF TERMS USED

A random sample of *operators* was utilized in each test so that inferences could be drawn about the respective test populations of operators, rather than about specific individuals. It is well known that individual operator differences exist; our primary interest here was in the interaction of the operators with the other variables studied. We, of course, hoped for small interactions so that recommendations about the other variables could be made which would apply to operators in general.

The *picking methods* employed will be referred to as the "roll" method, the "pick and throw-single object" method, and the "pick and throw-multiple object" method. With the "roll" method, the operator grasps the object to be removed with the thumb and forefinger; rotates the hand and releases the object into the palm. These motions are repeated until the hand is full, at which time the objects are placed aside. This is the method used almost exclusively in the peanut industry today. The "pick and throw-single object" method consists of grasping one object in the fingertips, and tossing it aside with a simple wrist motion. This method does not permit the hand and wrist to be rotated. The "pick and throw-multiple object" method is basically the same as the single object method, except two or more objects are accumulated before being placed aside.

The *picking positions* used in these tests were at the right and left sides of the belt, and at the end of the belt. In all positions, the operator stood facing the picking belt. At the right side position, the objects moved from left to the right of the operator; while at the left side position, the objects moved from the right to the left of the operator. At the end position, the objects moved toward the operator's field of vision.

The *damage content* denotes the percent of defective items in the objects to be picked. Since the defective and good items had about the same weight, this percent can be interpreted to be on a weight or count basis. In these tests, original or feed damage content levels of 2, 3 and 4 percent were used.

Density of objects on the belt is the ratio of the weight of objects per unit area of belt surface to the weight esblished as 100 percent density. The latter density is defined here as the maximum weight of objects per unit of belt area such that no objects rest on top of others.

Rate of flow of objects is given in the following manner:

$$\text{Rate of flow (pounds per minute)} = S \cdot W \cdot D \cdot M$$

Where S = belt speed in feet per minute
W = width of the belt in feet
D = density of objects on the belt (dimensionless)
M = weight of objects with a density of one, in pounds per square foot

Picking belt speeds were investigated in the range of 10 to 100 feet per minute. Special methods were necessary to investigate this variable because a change in the belt speed produces a corresponding change in the flow rate of both good and defective objects. Thus, the effect of variation in the belt speed would be confounded with the effect of variation in the flow rate of defective objects which is known to affect visual search time. In these tests, several belt speeds were investigated at constant flow rates which were maintained by appropriate changes in the density of the objects on the picking belt.

Operator learning is defined as the difference in picking rates between the various replications or trials of an operator performing the same set of tests. In most of these experiments, the learning effect became very small after the first replication. Thus, in most cases, the conclusions drawn from these tests are based on the second and third replications only.

RESULTS AND DISCUSSION—PICKING RATES

Operators—The results showing the differences in operator picking rates are given in Table 1. These differences were highly significant in the statistical sense, as

TABLE 1

Difference in Operator Net Picking Rate

Experimenter	Number of Operators Used in Test	Range of Mean Picking Rates in Pickouts Per Minute	Percent Difference between Fastest and Slowest, Based on the Average
Calhoun	4	95–106	11
Zimmer	9	80–102	24
Wright			
Replication 1	9	73– 95	26
Replication 2	9	81–102	23
Olivares	6	78–113	37

was expected. The small variation found by Calhoun can be attributed to the fact that a relatively small number of experienced operators were used in these tests. Fortunately, these operator differences did not interact appreciably with the important operating variables such as belt speed and picking method; thus, the effects of the other variables which follow can be interpreted to apply to operators in general.

Picking Method—The picking method found best in all tests where this variable was studied was the "pick and throw" method. In Calhoun's tests, the difference between the picking rates for the pick and throw method and roll method was 8.3 percent of the average of the two methods (1). This difference was significant at the .001 probability level. Wright found the "pick and throw" method resulted in a 6.2 percent and 4.3 percent higher net picking rate than the "roll' method for replications 1 and 2, respectively (8). This was significant at the 0.01 probability level. The difference between the single and multiple "pick and throw" methods was not found to be significant. The reason for the lower picking rate for the "roll" method may lie in the indecision of the operator as to retaining a good object in the hand. This theory is substantiated by subsequent data which show that the pickouts obtained by using the "roll" method contain slightly fewer good objects.

Although Wright found the interaction between operators and picking methods to be statistically significant, this effect is of little practical significance (8). He found for both test replications, that the same set of seven operators did better using the "pick and throw" method. Although the remaining two operators did better using the "roll" method, the superiority over the "pick and throw" method was negligible. From these results, a general recommendation can be made for all operators that the "pick and throw" method is best.

Picking Position—This variable was found by Wright to have negligible effect on the net picking rate (8). The choice of this variable can therefore be made solely on the basis of the requirements of the process in question.

Damage Content—Zimmer measured the effect of damage content on the picking rate (9). As expected, the higher damage contents gave higher picking rates because of the reduction in the visual search time, as well as the physical reach time. The picking rate was found to increase 7.4 percent for an increase in the percent defective in the feed objects from 2 to 4 percent.

Density—Belt Speed—Flow Rates—Zimmer conducted the first tests to evaluate the effect of belt speed (9). He used the following four density-belt speed combinations:

Density-Belt Speed Combination	Density (Percent)	Belt Speed (Feet Per Minute)	Rate of Flow (Pounds Per Minute)
1	100	10	7.75
2	25	40	7.75
3	15	70	7.75
4	10	100	7.75

The results of these tests, shown in Figure 2, indicate that the optimum belt speed is approximately 50 feet per minute. Due to the confounded effect of belt speed and

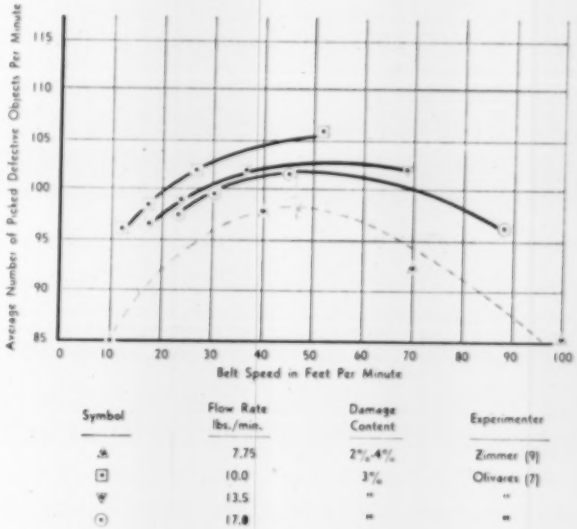

FIG. 2. Grand Average Picking Rate of Defective Objects as a Function of the Belt Speed for Flow Rates of Objects to be Picked.

density, it was not possible to say which factor had the greater effect on the picking rate. The tests conducted by Olivares were designed to answer this question (7). His objective was to determine if there were belt speeds common to a broad range of rates of flow of objects at which maximum picking rates and high quality of pickouts are obtained. The flow rates and density-belt speed combinations used were as follows :

		Belt Speed in Feet Per Minute at Flow Rates of:		
Density (Percent)		10.0 lbs/min	13.5 lbs/min	17.0 lbs/min
1	100	12.9	17.4	21.9
2	75	17.2	23.2	29.3
3	50	25.8	34.8	43.9
4	20	51.7	69.7	87.8

The results of these tests, also shown in Figure 2, indicate that such a belt speed does exist, i.e., at approximately 50 feet per minute, the same value found by Zimmer (9).

The picking rates observed by Olivares (7) were expected to lie below those found by Zimmer, since the flow rates used by Olivares were greater in all cases. This expectation was not realized because of the higher overall work pace of the operators used by Olivares. The latter results, however, do indicate that the effect of flow rate is moderate; i.e., a three percent decrease in the net picking rate in going from a flow rate of 10 to 17 pounds per minute.

Damage Content Interactions—The feed damage content was found to have little effect on the optimum belt speed and density combinations in Zimmer's studies (9). Both the two percent and four percent damage content feeds had optimum belt speeds of approximately 50 feet per minute.

RESULTS AND DISCUSSION—PERCENT GOOD IN THE PICKOUTS

Operators—This variable was found to have the greatest effect upon the number of good items in the pickouts. The results of the various tests, as shown in Table 2, were about the same for all three experiments. The wide disparity among operators may be attributed to the individual's ability or lack of same to direct his utmost

TABLE 2

Difference in Operator Picking Rate of Good Objects in the Pickouts

Experimenter	Number of Operators Used in Test	Range of Mean Percent Good Objects in the Pickouts	Average of All Operators
Zimmer	9	0.7– 7.3	4.0
Wright			
Replication 1	9	1.7– 8.6	5.4
Replication 2	9	1.0–11.4	5.0
Olivares	6	1.6– 8.4	4.7

attention, zeal, and manual skills to the job at hand; also the operator's judgment as to the relative importance of quantity vs. quality. This level of percent good objects in the pickouts would not prove too serious in most food processing applications where the economic loss associated with good items in the pickouts is small compared to the labor picking costs. This may not be true in the sorting of manufactured items of higher value. In these cases special training would be appropriate, including an adjustment of pace to maximize net process income.

Picking Methods—It was found that the difference between picking methods was significant at the .01 probability level for the second replication only of Wright's study. The "roll" method was superior to the "pick and throw" methods insofar as picking quality rate is concerned. For the second replication, the observed number of good objects picked per minute were as follows: "roll" method—4.0; "pick and throw-single object" method—5.4; and for the "pick and throw-multiple object" method —5.7.

Density—Belt Speed—Flow Rates—The average percent of good objects in the pickouts is plotted in Figure 3

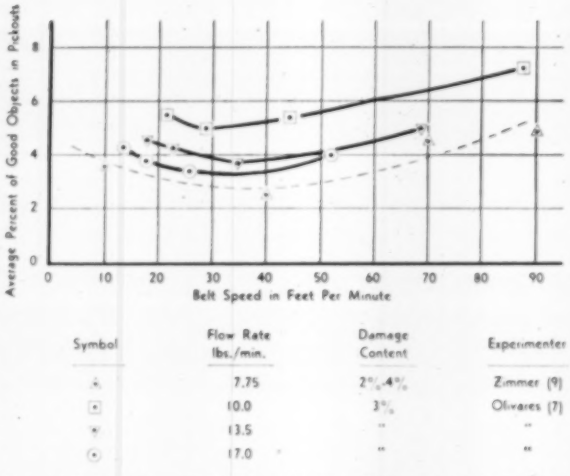

FIG. 3. Grand Average Picking Quality Expressed in Percent as a Function of Belt Speed for Each Flow Rate of Objects to be Picked.

for the same set of tests plotted in Figure 2. Figure 3 indicates that the optimum belt speed, again for all flow rates, is approximately 35 feet per minute. Further, the minimum points on these curves are actually rather broad regions; operation at 50 feet per minute, as suggested to optimize the net picking rate, will increase the percent of good objects in the pickouts by less than one percent in all cases.

SUMMARY

Considering only the picking operation design variables studied in these experiments, the picking position alone was found to be unimportant. The significant variables, listed in their order of importance, were the picking method, the belt speed, and the rate of flow of objects to be picked.

The pick and throw method was found to be superior to the roll method for net quantity of defective objects picked; average increases in the picking rate varied from 4 to 8 percent in the two sets of tests where this variable was studied.

The maximum net picking rate was found to occur at a belt speed of approximately 50 feet per minute for the flow rates investigated, i.e., from 7.8 to 17.0 pounds per minute. If the belt speed is lowered or raised by 25 feet per minute, the net picking rate decreases approximately five percent. Although the maximum picking quality was found to occur at a belt speed of approximately 35 feet

TABLE 3

Explanation of Experiment Design Terms

Factor	Code Letter	Subscript	Number of Levels	Type Variable
Operators	o	i	$i = 1, 2, \cdots, 9$	Random
Method	M	j	$j = 1, 2, 3$	Fixed
Position	P	k	$k = 1, 2, 3$	Fixed
Residual or Experimental Error	e	ijk		Random

per minute, this should not, under ordinary circumstances, effect the choice of belt speed because its effect on the variable is relatively small.

The flow rate of objects to be picked had the smallest effect of the three design variables found to be significant in these experiments. Since only a limited amount of information was obtained on this variable, it can only be said that the flow rate should be kept as small as possible, consistent with production requirements, to maximize the net picking rate.

If the recommended picking method, belt speed, and flow rate are employed, it should give an increase of about 10 percent in the net picking rate as compared with the usual practice in the peanut industries today.

APPENDIX

DETAILED EXPERIMENTAL RESULTS OBTAINED BY WRIGHT

Wright (8) studied the effects of "picking methods" and "picking positions," as defined in the section on "Discussion of Terms Used"; in statistical terminology, these were treated as fixed effects. A total of nine different operators were also included as a random type variable to determine the extent to which the effects of the first two variables change from one operator to another. The model equation for this experiment is given below where Y_{ijk} denotes the net rate of picking defective objects for the ith operator using the jth picking method and the kth picking position. An explanation of the other terms used in this equation are given in Table 3.

$$Y_{ijk} = \mu + o_i + M_j + P_k + oM_{ij} + MP_{jk} + e_{ijk}$$

The analysis of the observed values of Y_{ijk} given in Table 4, is summarized in Table 5. A lucid presentation of the method of obtaining the expected values of the mean squares for a mixed model experiment which contain both random and fixed type variables is given by C. R. Hicks (3). Similarly, the method of breaking down a factor into individual degrees of freedom is treated quite well by Cochrane and Cox (2).

The results of the analysis given in Table 5 indicates that the operator differences were highly significant as expected. The only other significant main effect was that due to picking methods. The single degree of freedom breakdown of this factor indicated that there were no differences between M2 and M3, i.e., the two "pick-and-throw" methods, but only between the "pick-and-throw" methods and the "roll" method.

The only significant interaction found in this experiment was the operator × method interaction. Fortunately this was a "weak" interaction of little or no practical significance; the latter conclusion being reached by analyzing the original data given in Table 4. Thus, from Tables 4 and 5, two quite general conclusions could be drawn.

1. The "pick-and-throw" picking method is superior to the "roll" method for practically all operators. Further, there is no significant difference between the "pick-and-throw-single-object" and "pick-and-throw-multiple-object" methods.
2. There is no significant difference between the three picking positions studied in this experiment, for all operators.

TABLE 4

Observed Number of Defective Objects Picked per Minute Based upon a Three Minute Test Run

	P1			P2			P3		
	M1	M2	M3	M1	M2	M3	M1	M2	M3
o1	71.33	76.00	93.67	72.67	80.67	84.67	66.00	87.67	79.33
o2	84.33	86.00	93.00	80.67	93.67	91.67	80.67	87.33	93.33
o3	92.00	89.00	86.67	89.67	87.67	92.67	94.00	93.33	72.33
o4	71.67	79.67	76.67	77.33	84.67	77.33	71.33	85.67	79.00
o5	79.33	88.33	89.00	83.00	86.67	80.33	87.00	88.67	82.00
o6	73.67	75.67	84.33	77.00	85.00	81.67	75.67	74.33	79.67
o7	70.00	76.00	68.33	73.67	71.33	73.33	75.67	71.33	76.00
o8	76.33	74.67	88.33	72.33	79.00	85.00	76.33	72.67	84.00
o9	89.67	103.00	99.67	85.33	96.67	100.67	93.67	92.00	93.33
Average	78.60	83.06	86.54	78.96	84.95	85.17	79.96	83.58	82.03

M1—"Roll" method
M2—"Pick-and-throw-multiple-object" method
M3—"Pick-and-throw-single-object" method
P1—Right side position
P2—Left side position
P3—End position
o1—Operator 1
o2—Operator 2, etc.

TABLE 5

Analysis of Variance

Factor	Expected Mean Squares	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Remarks
o	$\sigma_e^2+M P \sigma_o^2$	3,436	8	429.5	$\frac{429.5}{21.6}=19.9^{***}$	
M	$\sigma_e^2+P\sigma_{oM}^2+Po\sigma_M^2$	460	1	460	$\frac{460}{52.8}=8.7^{**}$	$M2+M3$ Vs. $M1$
		5	1	5	$\frac{5}{52.8}=0.1$	$M2$ Vs. $M3$
P	$\sigma_e^2+M\sigma_{oP}^2+Mo\sigma_P^2$	22	1	22	$\frac{22}{17.3}=1.3$	$P1+P2$ Vs. $P3$
		2	1	2	$\frac{2}{17.3}=0.1$	$P1$ Vs. $P2$
$o\times M$	$\sigma_e^2+P\sigma_{oM}^2$	844	16	52.8	$\frac{52.8}{21.6}=2.4^{*}$	
$o\times P$	$\sigma_e^2+M\sigma_{oP}^2$	137	16	8.6	$\frac{8.6}{21.6}=0.4$	
$M\times P$	$\sigma_e^2+o\sigma_{MP}^2$	49	1	49	$\frac{49}{21.6}=2.3$	$M1$ Vs. $M2+M3$ Vs. $P1+P2$ Vs. $P3$
		36	1	36	$\frac{36}{21.6}=1.7$	$M2$ Vs. $M3$ Vs. $P1+P2$ Vs. $P3$
		0	1	0	0	$M1$ Vs. $M2+M3$ Vs. $P1$ Vs. $P2$
		25	1	25	$\frac{25}{21.6}=1.2$	$M2$ Vs. $M3$ Vs. $P1$ Vs. $P2$
Residual	σ_e^2	692	32	21.6		
Total		5,708	80	1,081.5		

* Significant at the .05 probability level.
** Significant at the .01 probability level
*** Significant at the .001 probability level.

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President's Message

GEORGE H. GUSTAT
President, American Institute of Industrial Engineers, Inc.
1958-59

Tomorrow's Problems, Today's Opportunities

THIS will be the last of these presidential messages that have been my privilege to write for the *Journal* of the American Institute of Industrial Engineers.

One of the most rewarding experiences that I have had in this office has been the great number of favorable comments both written and verbal about these articles. It is indeed reassuring to know that so many individual Industrial Engineers do take a broad and enlightened look at the profession that gives them their livelihood.

The progress of the AIIE in the last year has also been a gratifying experience. Not so much because of our growth, but because of the enhancement of our professional prestige.

For instance, early in the year our Institute was one of the sponsors of the Pan American Federation of Engineering Societies' Convention at Montreal. This gets the name of Industrial Engineering in the professional spot light with the other fields of engineering on a very high plane. We are being asked to co-sponsor the ASME and the AIEE in some of their future Engineering Management Conferences.

For the second time, we jointly sponsored a Systems Simulation Symposium with ORSA and TIMS.

In my travels around to visit chapters and through information passed on to our Publicity Director, I find a great many of those chapters, on a local basis, jointly sponsoring with other engineering and science societies, science and engineering programs for the high school students and the public of their communities. In a great many instances the Industrial Engineering chapter has been the key moving force in these splendid endeavors.

The term Industrial Engineer, thanks to the activities of the AIIE, is beginning to be understood and respected by both our fellow engineers and scientists and the public at large. We have a fine beginning and I am sure that we are on our way.

One of the more important instances of recognition has been our acceptance by the Engineers Joint Council as a constituent member and the invitation to occupy space for our national headquarters in the proposed United Engineering Building. In addition to sharing clerical forces, conference rooms, office equipment, library facilities, etc. with the other engineering societies, this will prove a marvelous vehicle for even better acceptance of our field by everyone. Any publicity that accrues to engineering generally is bound to be helpful to us and all of the other groups that will occupy this fine building. There are probably those in our membership who will personalize all of the activity that the Institute engages in and may not appreciate the value to them of these types of publicity.

It is my firm conviction that our immediate supervisors and the executives of our companies will come closer to knowing what Industrial Engineering is, and to have

considerable respect for it through these media. It can not help but be of material benefit to each of us who is practicing to have the attitude of these people improve towards the name, "Industrial Engineering." These men probably go to New York City oftener than to any other city in the country and they will in the future see the new United Engineering Building, and they can not help but be impressed towards the whole field of engineering. This will be a central place where government agencies, educational institutions, as well as all businesses will go to get engineering information. To be a part of this will, without a doubt, enhance the prestige of all Industrial Engineers.

In the future, engineers must achieve the same type of unity that the medical and legal professions now enjoy. Our Professional Relations Committees are doing a wonderful job in working with all other engineering societies to accomplish this. It is the type of work that every practicing engineer should solidly support for it will have a decided influence on what the world in general and his company's executives think of him.

Better acceptance of Industrial Engineering work and the Industrial Engineers will assume even greater importance as the problems of modern industry and business enterprises grow more complex.

The problems of the world of the future will affect all of us and particularly all of the engineers and perhaps the Industrial Engineers more than any of the others.

Consider the impact of some things that we are relatively sure will happen. The following statistics are from an article by a group of prominent scientists in the January issue of *Nation's Business*. Our present population of approximately 180 million people is estimated to grow to approximately 200 million by 1965. The number of married couples is estimated to increase by approximately 8 million.

The labor force will increase by approximately 25 percent. There will be many changes in its make-up. The number of women in proportion to men will increase, the average age will probably drop, and there will be an increase in the number of part-time workers. The shortage of scientific and professional personnel will continue to be critical.

Gross national product will go from 436 billion dollars per year to 570 billion, personal income from 357 billion to 450 billion and employment from 65 million to 76 million by 1965 and to 97 million by 1970.

These men looked a lot further ahead than 1965, but the figures became so astronomical that they are almost beyond comprehension.

The same sort of growth in population is occurring in the rest of the world and particularly in those countries where the living standard is relatively low. The international problems arising from these circumstances are extremely serious and will affect the entire world. These economists predict that the total world population will increase from 2½ billion people to 3½ billion by 1970. Contemplate for a moment the terrific impact that growth of this kind will have on the economic and social structures of the world.

Just producing enough food for this number of people is going to be quite a task. One of the very serious problems in this connection will be the supply of water. While there is plenty of this life sustaining commodity, it always seems to be located in areas that are not well adapted for year around production of food, or it is in an unusable form such as sea water.

There are many interesting engineering problems that will develop along this line. In a dream stage, at least, is a consideration to run a pipe-line from the Great Lakes to the arid Southwest. Think of the new industries that this could create. Another fascinating experiment which holds great promise is one that reduces the surface tension of salt water so that it can economically be converted to fresh life giving water. The development of cheap power is a must in this connection, and a good deal of research is going on in this area.

The future holds many interesting developments in other fields as well, and all, of course, will bring many new problems for the engineers to solve.

As a result of the space explorations, we will probably have more accurate weather forecasting and perhaps some day a modest control of weather. The implications of this on all business enterprises and professions can be profound.

Improved world communication is almost certain to result. Our scientists can foresee static free, high quality, uninterrupted and economic radio and television transmission all over the earth.

Rocket transportation anywhere in the globe and to other planets is just around the corner.

The discovery and use of exotic fuels such as boron and nitrogen compounds in rockets place them only a step away from everyday use in the more conventional forms of transportation.

Whole new industries will be formed and a great many old ones altered to take care of these advances.

The developments taking place in harnessing solar energy, new chemical batteries, nuclear and thermonuclear power generation, use of winds and tides for power generation, and generation of electric power without going through heat transfer and rotating machinery are wonderful to contemplate.

These are developments that are bound to take place, and they will perhaps be able to help supply the necessities and luxuries which the expanding population of the world will demand. All of these problems are certainly going to change the face of our activities in the future, and they do emphasize the urgent need for better long range planning.

We will have to try to picture these changes so that we can estimate future customer requirements, business

opportunities. and to evaluate possible competing products and systems of the future.

It is not necessary or practical to wait until these problems arrive. We can plan what this future environment will be like by synthesis. This would involve broad scale physical feasibility studies, preliminary system designs with reasonable allowance for flexibility so that as actual data are collected the systems can be practically modified. Just starting such studies is of great value; for as information is fed back to management, it stimulates new concepts and improvements. Above all, such synthesis provides the means of evaluation.

All of this has a familiar ring for what it is pointing up is the use of applied operations research techniques such as simulations, regression analysis, correlations, and, above all, a liberal use of imagination.

A great deal has been said about the change that is taking place in the Industrial Engineering profession, and all these problems of the present and the future certainly indicate why that change is taking place. In this view, the practice of Industrial Engineering has probably changed more in the past ten years than any other branch of engineering. The present level of practice probably varies more than any of the others. Some companies are still doing Industrial Engineering work at the level of rate setting, while others are completely up-to-date and are using in their everyday work the techniques of operations research on their expanding problems.

The specific problems that we can see ahead for Industrial Engineers are:

1. Investments in productive equipment will continue to increase because of higher degrees of mechanization. This will mean broader studies to integrate combination of operations into the production and distribution systems to produce more and more goods in a given period of time. Equipment capable of producing at these rates is bound to have an effect on inventory size, delivery schedules, space requirements and perhaps most of all on the enterprise's planning from sales forecasts to production schedules.
2. Knowledge of the developments in other fields of engineering is becoming a must for the Industrial Engineer. A great deal of the automatizing of operations should be stimulated by the Industrial Engineer, and he can only do this if he knows something about other developments. For example, the great progress in measuring through means of air pressures, fluid flows, sound waves, light, etc. in the past twenty years has been phenomenal. More and more of these techniques can be built into the productive machines as an integral part of such equipment.
3. Careful evaluation of such investments and alternative plans will become increasingly more important. No one likes to risk this much capital lightly. Many managers fear that high capital investments of this type will raise break-even points by increasing fixed costs. Many considerations must enter into decisions of this kind; the future value of money compared to the present; the increased danger of obsolescence of the higher value and more complex equipment, and the increased dangers of breakdowns by combining several operations into one.
4. When we swap physical skills and effort for mental abilities, we have a profound effect on the attitudes of the workers. Better training programs must be instituted, and care taken when designing these systems that job challenge and content are not lost.
5. Measurements' objectives will probably change from keeping people busy to keeping the investment busy. Management controls will have to be sharper and more sensitive because of the large amounts lost when use of high investments are not optimized.
6. The ratio of direct operators to indirect has been changing and will change even more. The number of indirect will increase and direct will decrease. When I speak of indirect, I am including all salaried staff as well as the hourly paid indirect workers. The Industrial Engineer of the past has made a large contribution to controlling the direct, but the indirect has hardly been touched. Here, indeed, is a lucrative field of work. It is not easy, because there are seldom objective measures for this type of work. Evaluation of contributions of these indirect workers is extremely difficult. The nature of these costs tends to be fixed unless such measures and evaluations can be developed. These people tend to become specialists in one field or another and getting them to take a broad management viewpoint is difficult.

These are things that are happening to us right now and are the factors that make the Industrial Engineering field such a dynamic one.

The educational institutions, of course, recognize these trends and have strengthened the Industrial Engineering curricula to help take care of it. More and more of the universities have set the Industrial Engineering curricula up as a separate school, and the education the men receive is improving all of the time.

If you hire an Industrial Engineer from a university whose curricula has been accredited by the Engineers' Council for Professional Development; and remember the American Institute of Industrial Engineers has a strong voice in this; you have a man who has been given some pretty sophisticated training.

Many other agencies are recognizing that more training is necessary and courses and seminars are the order of the day.

Much of this training is in the field of engineering mathematics, and they allow us to recognize, analyze, and solve many of these broader problems of which I speak.

I am sure all of you have seen lists of the various mathematical names that have flooded technical literature in the past few years. I am not going to redo such a list, but it may be worthwhile to examine the nature of some of these concepts.

1. *Non-Random Analytical Methods*

   In a large number of our studies, we are concerned about relationships among two or three variables. In such cases familiar mathematical methods are usually adequate. For example, break-even charts can be formed with a knowledge of algebra. Simple economical run size formulae have been developed using methods of differential calculus. Most Industrial Engineers understand and have used this kind of thinking.

2. *Analytical Techniques Involving Random Variables*

   In many operations we can not directly predict what will happen. We can only say what will "probably" happen.

A number of random variables may affect such operations causing them to yield a varying output. Such operations, or processes, are said to be "stochastic processes," and mathematical methods have been developed to help us in analyzing them. Such probability models as acceptance sampling tables, control charts, machine interference (or other waiting line) formulae and many of our regression formulae can be helpful in describing stochastic processes. In general, statistics are of great aid in handling situations involving a number of variables which we can not economically chase down individually. Here again, the engineer has good background for understanding, but has only recently started to use this kind of an approach.

3. *Modern Methods of Mathematical Analysis*

In operating (or in designing) our production systems, we find there are many "possible" ways of:

a. Meeting a schedule
b. Building capacity
c. Solving a problem

It may be intuitively obvious that there is one best way to run the operation, but since there are so many alternatives, it becomes difficult to "home in" on the one best alternative. In this connection, let's examine two of the very useful approaches that have not been as well understood or used. Indeed, it may well take some additional training for effective use.

a. *Analytical Methods Useful in Handling a Large (but finite) Number of Variables.* Mathematical Programming, "Dynamic" Programming, and Game Theory are some mathematical methods useful in helping to home in on the best way to allocate existing facilities towards meeting our goals. These methods often require the aid of electronic computers in achieving a solution. They promise to be one of the more practical methods by which our processes can be run profitably as they become more costly and complex.

b. *Simulation Methods.* One such technique is called Monte Carlo Analysis. This takes into account the random or statistical variations as well as the systematic variations under our control. A flow diagram, probability distributions, and random numbers are used to form a model which simulates the predictable and unpredictable variations in the operation. By running this simulation model "on paper" we can predict the effects of changes in the "real" operation without disturbing it.

I believe that much effort will be put into this "middle ground" of mathematics which is needed to analyze systems involving many variables, some of which are related systematically and some of which are stochastic.

These represent knowledge that the Industrial Engineer must acquire to supplement his present know how in order to handle the more complex problems of today and the future.

In summary, then, it seems to me that we will be spending more time studying systems of operations and how they interact. To do this, we will make more use of mathematical models to characterize relationships within and among operations.

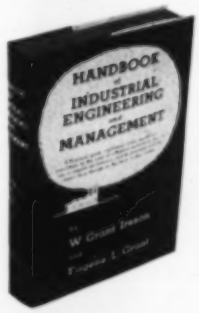
One of the more challenging aspects of all this is that we will have to design systems around the people who operate them, and to take into consideration their needs, desires, and rights if those systems are to be effective.

More and more we will have to work with many other management staffs so that management will not have to piece together the results of many such studies in envisioning the effects of changes to the productive system.

In all of this, the American Institute of Industrial Engineers will take an ever-increasing role in the education and professional development of the Industrial Engineer to help him fulfill his destiny as a leader in progress.

HANDBOOK

Industrial Engineering AND Management



Edited by W. G. Ireson and E. L. Grant

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Summary of the Industrial Engineering Symposium, Georgia Institute of Technology, November 1957

Reported by **CECIL G. JOHNSON**

Georgia Institute of Technology

This Symposium was the fourth in an annual series sponsored by the Long Range Planning Committee of AIIE. A brief summary of the previous meetings is given to introduce this report on the Fourth Symposium, held in Atlanta, Georgia, on November 7 and 8, 1957.

- *The first meeting*, held in St. Louis in 1954, essentially expressed the need for a definition of the scope and objectives of Industrial Engineering. This meeting further emphasized the need for the Professional Industrial Engineer to give operational proof that Industrial Engineering is utilizing new fields of science in its problem-solving activities.

- *The second meeting*, at Cornell University in 1955, developed the current definition of Industrial Engineering as a *guide* for AIIE. This comprehensive definition, however, created a problem of interpretation for both lay and professional groups.

- *The third meeting* was held at Purdue University in 1956, and here the definition was interpreted for a better understanding by management, employees, engineers in other staff groups, and the general public. An important question was raised concerning the definition of *system* and *systems design* as understood and used in the formal definition of Industrial Engineering. From this discussion a fresh approach was suggested toward defining Industrial Engineering by the presentation of case studies that would particularly depict the dynamics of systems design.

- *The fourth meeting*, held at Georgia Tech, continued this development by the examination of several selected case studies. These cases were presented, discussed and analyzed in order to clarify the role of Industrial Engineering analysis and design.

CASE I

Warren Alberts, Director of Industrial Engineering for United Air Lines, presented a case study on the Analysis and Design of an Airline Reservation System.

The over-all operation of an airline, both from a profit and passenger service standpoint, is extremely dependent upon the speed and accuracy with which it handles and controls the space it has for sale.

United Air Lines' management, in 1955, decided on an over-all analysis of the company's reservation function, including the possible design of a system which would take care of its projected needs through 1965. The system at that time employed over 2,000 people, cost approximately $12,000,000 a year to operate, and was handling up to 50,000 transactions a day. This system could be visualized as a large information processing complex covering some 80 stations spread throughout the country.

The Industrial Engineering Department of United Air Lines, which includes such functions as Work Analysis, Operations Research, Systems Engineering, and Organization Planning, undertook the direction and leadership of this study. A study team was established and given the assignment to:

1. Step back and analyze the entire system.
2. Isolate the basic problems.
3. Measure the key variables and project the system and its requirements 10 years into the future.

To help the team concentrate on developing requirements, their initial goal was set as the development of a functional specification. This first phase took approximately a year to complete. Basic problems such as time lags, exposure to human error, divided responsibility, and the inability of people within the system to audit their work, were highlighted. Problems susceptible to short range solutions were turned over to operating groups and an interim system, utilizing IBM Ramac computers at Denver connected to transceivers in the largest reservations offices, was installed.

The functional specifications which contained volumes and desired service levels in very specific terms soon pointed up the limitations of existing electronic hardware and communications networks.

A second phase, that of system design and translation

of the functional specification into a technical one, was undertaken. Stanford Research Institute was called in as a consultant to evaluate existing technology and help specify a realistic system. Concurrent with the development of technical specifications, a complete economic analysis of existing manpower and machine costs, along with the value of meeting specific design requirements, was made.

This system study, which spanned a period of two years, finally resulted in the procurement by United of a highly advanced electronic reservations system which will not only meet its specifications, but also make an important contribution to profit and increased productivity. The study also pointed up the need to consolidate certain functions basic to the system and which previously had been spread out among several departments. These organizational changes were made.

The project dramatically highlighted the importance of taking an over-all Industrial Engineering approach to the analysis and design of complex systems which involve both technical and human aspects. An important point in the approach taken is the development of system requirements which manufacturers are asked to meet versus the current practice of trying to adopt and integrate existing hardware to meet business needs. The results, both in satisfying the company's requirements and in improving productivity, point up the value of allocating Industrial Engineering effort to the research and development of business systems.

CASE II

Richard Forberg, Director, Industrial Engineering Division, Procter and Gamble Company, presented a case study of the Design of A Synthetic Detergent Production and Distribution System.

A system to produce and distribute synthetic detergents was presented as a whole. The major information flows and the product flow were indicated schematically.

The system was divided into sub-systems, each of which was a major project area. The work on the subsystem for production scheduling and inventory control was presented as a typical project. This study team developed a production scheduling procedure which considered all the significant costs and reduced the time lags in decision making. Installation of the improved system involved simulation, parallel runs, and limited scale tests.

Another sub-system discussed briefly was the mechanized material handling of packaged, finished product. Equipment components for such systems have become commercially available. Designing an integrated system to perform over a wide range of expected levels of consumer demand and modifications of product mix required a total system approach. The use of the Monte Carlo method of simulation was planned to test alternative designs.

A third sub-system involved the processing of customer orders on electronic data processing equipment. Orders were taken on mark-sense cards by salesmen. A system to process all subsequent paper work necessary for shipment, accounts receivable, sales analysis, and product inventories was under design.

The key role of the Industrial Engineering Division in system design on these separate projects and for coordination at the corporate level was emphasized.

CASE III

George Gustat, Director, Industrial Engineering Division, Eastman Kodak Company, presented a case study of the Mechanization of A Finishing Operation.

An industry was pictured that had successfully employed Industrial Engineering for many years. It has used ideas such as measured work, cost control, quality control and scheduling to strongly aid the organization. In an economic climate of rising input costs Industrial Engineering had contributed to holding the costs to such a level that it was unnecessary to raise sales prices. However, an expanding market demanded an accelerated growth in production. This, coupled with technological complexity, required that planning be shifted from a five year basis to projections of ten and fifteen years. The conventional methods of Industrial Engineering then being employed were no longer adequate.

A mixed team was used to assess the situation aggressively. A large number of new ideas were presented and scheduled to be worked out and installed in the next ten years on a scheduled priority basis. These suggestions ranged from very minor ones to complete revisions of the productive system.

One of these ideas was presented to demonstrate the development of this improvement scheme. In this case large quantities of product were being inspected in a rigorous manner to get a product with a low defect rate. To attack this potential problem more effectively, it became necessary for the Industrial Engineer to form a part of a specialized team. It was emphasized that an Industrial Engineer oriented to his restricted techniques would have had little success with this problem requiring as it does technical knowledge from other fields. Since the present operation was profitable, there was a considerable tendency to multiply the existing types of facility to meet the new demands. A complex machine was developed to replace the human inspection and handling previously employed. The evolutionary development, testing, installation, and redesign were continued over an extended period with a follow-up of Industrial Engineering techniques applicable to an expensive man-machine work unit. Now, the new machine produced a systems scheduling problem for the Industrial Engineers that required a more sophisticated solution.

The success of this productive equipment influenced the expansion plans. Here it was noted that each progressive and needed change in the system caused more

changes involving more coordination and planning in the over-all system. In summary, the over-all economic influences and pressures caused Industrial Engineering to become oriented toward an expansive dynamic improvement program. The narrow and admittedly static concepts of thinking previously used were now being directed toward a broader and more progressive view of the system and the larger potentials for use of resources.

CASE IV

L. T. Ohmart, Manager, Industrial Engineering Department, Armstrong Cork Company, presented a case study of Organization for Systems Design.

The modern national trend in Industrial Engineering has continued to emphasize systems engineering. This has resulted from the realization that Industrial Engineering problems cannot be completely divorced and isolated from their environment. For the Industrial Engineer to properly function, it is necessary that he become less specialized and have a good command of the broader Industrial Engineering functions.

To better serve the needs of making and marketing a competitive product an interesting organizational change was reported. Specialization was deemphasized and individuals with broad scope and background were assigned to areas of functional responsibility. These individuals were grouped into a developmental team that had successive responsibilities as a new product was developed and marketed.

A case study was presented showing the accelerated and coordinated stages employed as a floor backing was successfully moved from research to production. The group of broadly oriented personnel composed a small coordinated team that now employed various specialists as internal consultants. As the product progressively developed on a time scale each responsible member of the team could draw on specialists to assist him in accomplishing his part of the mission. The team members were generally drawn from production, research, project engineering and Industrial Engineering.

Successful experience in this organization has shown that if systems engineering work is to be effective, responsible staff people must know and respect what effects their actions will have on other parts of the organization. If the Industrial Engineer is to participate in this system, he should develop a perspective that enables him to look at any problem as an internal part of the whole system.

This orientation of thinking had also been demonstrated to be excellent training for handling emergency systems problems.

THE EMERGING ROLE OF INDUSTRIAL ENGINEERING

From these isolated case studies, what are some of the major and distinguishing general aspects of Industrial Engineering?

1. The concept of opportunity-oriented solutions to problems.
2. The concept of Industrial Engineering as a continuum for all management levels.
3. The concept of the emerging role of the Industrial Engineer in a dynamic profession of engineering.
4. The concept of Industrial Engineering as a research, development and creative staff function rather than a line-staff function.
5. The recognition of the similarities of the Industrial Engineering systems concepts with those of other branches of engineering. A recognition of some of the distinguishing differences, such as the emphasis on the human component, economic orientation, degree of predictability and probabilistic nature of problems.
6. The recognition of the inadequacies of both measurement techniques and the Industrial Engineering orientation toward measurement.
7. A recognition of the inadequacies of information about communication from the viewpoints of man-to-man, man-to-machine, or machine-to-machine transfers. Systems design is of course critically dependent upon knowledge of this type.
8. A recognition that both the practicing and academic Industrial Engineer is broadening his intellectual scope as he views and practices Industrial Engineering.

FURTHER PLANS

In the next issue of the *Journal* the report of the 5th Symposium held at the State University of Iowa in November, 1958 will be published. This symposium was devoted to a consideration of some of the problems of developing a common technical language in the profession, and further delineates the "Emerging Role of Industrial Engineering."

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Recent Readables

AUTOMATION

"The Role of Existing Computer Techniques in Statistics and Quality Control," by M. E. Muller, INDUSTRIAL QUALITY CONTROL, *page 10, March 1959.*

Areas where electronic computers can make positive contributions today in the field of statistics and statistical quality control are: 1. Administrative Control, 2. Data Processing, 3. Technical Computations and 4. Simulation Research. In this article the author attempts to give a general outline of some of the applications of computers to these areas, quoting specifically the particular programs with which he is most familiar.

COST CONTROL

"Cost Controls Pay Off Big," Survey, CHEMICAL AND ENGINEERING NEWS, *page 21, February 16, 1959.*

Most chemical companies surveyed have had cost cutting plans in operation for several years; the 1957-1958 recession speeded up such plans. Cost control programs are comprehensive, hit every phase of operations. Biggest industry effort went into making employees cost conscious. When a company makes it clear it expects results, a cost control program usually succeeds.

"Cost Control—Past, Present, and Future," Editors, FACTORY MANAGEMENT AND MAINTENANCE, *page 63, March 1959.*

Factory editors went to Phil Carroll for an updating on industrial cost control. He was asked:

What does the history of scientific management tell us about cost control? Where do we stand today? In what direction will we be moving in the next 10 years? Here is what Phil Carroll sees:

1. What The Early Days Taught Us
   a. Cost variations must reflect managerial performance, not volume dips and rises.
   b. Constant costs for people and equipment can't be altered by switching production to "low cost" departments.
   c. Managerial improvements in production inherently raise the rate and the amount of overhead.
   d. Overhead costs must be broken down and assigned according to product, process, markets, and customers.
   e. Cost-control measures must be designed for managerial use, not for accounting purposes.
2. Where Cost Control Stands Today
   a. Flexible budgets have reduced some of the cost confusions.
   b. Supervisory incentives are helping to pin down cost facts and to assign responsibility, but . . .
   c. We're still too careless about money.
   d. Budgets based on averages won't help much.
   e. Productivity increases will depend upon improvement of indirect labor efficiency.
   f. Ignorance of product costs is still the weakest link in cost control, and . . .
   g. Managerial errors, not employee indifferences, are still the biggest cause of cost leaks.
3. How The Future Looks
   a. Managers will have to know more about accounting than the accountants do.
   b. Industry must wake up to the fact that managers lose as well as make profits.

e. We will need many more facts if we are to cut control lag and reduce errors.
d. We must, of necessity, build control indicators that sort out overheads, separate cost variances that result from arithmetic, and measure indirect work. And finally . . .
e. Managers must learn to convert cost controls into profit-making action.

"How to Control Handling Manpower," by B. W. Hupp, MODERN MATERIALS HANDLING, *page 77, January 1959.*

Some companies maintain a stable force regardless of fluctuations in work load. Others, because of competitive pressures, must hire and lay off men as the work load changes. This article shows how costs can be used as a guide to proper levels of employment.

CREATIVITY

"Does Brainstorming Work?", by E. C. Nevis, MACHINE DESIGN, *page 144, October 16, 1958.*

Social psychologists have shown that there is no such thing as a "group mind" or "group think." There are only individuals who think. But when cooperating with each other or stimulated by each other, all can improve the caliber and productivity of their own thinking and arrive at solutions to problems. Brainstorming may be a valuable technique when used appropriately. However, much more systematic research is needed before we can draw firmer conclusions about its value.

"The Ideal Creative Supervisor," by E. Raudsepp, MACHINE DESIGN, *page 30, October 16, 1958.*

The creative-group supervisor has to have a well-rounded set of abilities—not only in technical matters, but also in personal leadership and handling of his group. But what are the specific characteristics required of the "ideal" supervisor?

A panel of experts—105 of them—on various phases of creativity was asked this question. Their answers have been presented in this series of three articles. Previous articles were in the September 18 and October 2 issues of *Machine Design.*

MATERIALS HANDLING

"Developments in Scrap Handling," by Editors, MATERIAL HANDLING ENGINEERING, *page 68, March 1959.*

The proper handling of scrap can mean added profits to a manufacturer. It can also mean life or death to an organization whose only income is derived from the sale of this kind of material. Here are examples of how companies of both types use material handling equipment and systems to make their scrap handling fast, efficient, and clean.

In February 1957, *Flow* published an extensive survey about scrap handling. In this issue *Material Handling Engineering* reports on variations and developments in scrap handling as it is done by cost-conscious companies.

METHODS ANALYSIS

"$500,000 From Better Methods," by S. Carlin, FACTORY MANAGEMENT AND MAINTENANCE, *page 78, March 1959.*

Operations analysis is piling up savings of $500,000-a-year at Carrier Corporation. Over-all economies are in the order of 15 to 20 times the cost of running the Operations Analysis (O.A.) department.

Carrier's O.A. department has just four analysts. They are carefully chosen from within the organization.

Analyses are broad, comprehensive. For example, an analysis doesn't study scrap disposal at a specific machine. It deals instead with all plant cleaning, scrap collection, disposal.

The methods aren't unusual. The analyst uses the mathematical techniques of operations research—without getting too sophisticated.

Recommendations are developed in close cooperation with operating supervisors. Line supervisors approve final proposals before they go up to general management. And line supervisors put the approved changes into effect. O.A. men make six-month follow-up reports on how the changes are working out.

"Handling at the Work Place," by The Editors, MODERN MATERIALS HANDLING, *page 91, February 1959.*

Today, horrible examples of workplace layout exist; nine times out of ten, not because of a lack of available knowledge or equipment, but rather because of a lack of attention by someone who knows what can be done.

This, the first in a series of articles, will show not only what can be done but also how it is being done in well-run plants. Starting with the basic principles, it then covers the types of equipment available and the methods through which this equipment is being put to work.

OPERATIONS RESEARCH

"Formulating a Linear Programming Model for Refinery Simulation," by C. R. Nichols, THE OIL AND GAS JOURNAL, *page 101, February 1959.*

Linear programming is a powerful tool for arriving at the right operating decision to realize maximum profit while still meeting all production requirements. This article deals with the building of a model to adequately define the refinery system in question.

"Waiting Line Theory," by S. B. Smith, MODERN MATERIALS HANDLING, *page 94, February 1959.*

Up to now, many decisions on capacity have been based on judgment. Waiting line theory, or queueing theory as it is often called, offers a means of reducing the amount of that judgment. It is a method of analyzing capacity needs under changing demands. It does this by predicting the effects of providing various capacities.

There are two methods of solving waiting line problems. The first is an analytical approach. It involves selecting standard distribution curves to fit the sample distribution of arrivals and service times. Then formulas based upon probability theory are used to get information on the expected delays and the waiting line.

In cases where arrivals and service times cannot be approximated by standard distributions, analytical methods cannot be used. In cases like this, a problem can usually be solved by using the Monte Carlo technique.

"You're on the Management Team" by E. R. Sims, Jr., MATERIAL HANDLING ENGINEERING, *page 71, March 1959.*

Material handling engineering has come of age. It is now far more than a plant function designed to cut operating costs. Today, the material handling engineer must consider himself a businessman in every sense. He must understand the total concept of physical flow through the economic system. He must interpret management policies and objectives in terms of control systems and handling equipment to maintain the continuity and efficiency of the blood stream of the physical functions of our economy.

A recent trend in management is to apply the systems approach to business analysis. This is the basic concept underlying such new techniques as operations research and the military's weapons systems analysis procedure. The concept is based upon assumption that any series of actions in an integrated system has caused an effect relationship which can be described in a logical or mathematical manner.

When seen in its relationship to the logistical system of busi-

ness activities, material handling might better be defined on a functional basis as, that portion of the business system which affects the relationship of materials and packaging to the product, facility, or customer without adding usable worth or changing the nature of the product.

PREVENTIVE MAINTENANCE

"This PM Program Fits Anywhere," by K. H. McBrady, FACTORY MANAGEMENT AND MAINTENANCE, *page 61, January 1959.*

This food processing company designed a preventive maintenance program to fit the needs of any of their 28 plants. These plants process some 200 varieties of food, feed and pet food. The maintenance force varies from 3 to 130 craftsmen depending on plant size.

The program they developed has these five objectives:

1. All equipment must be regularly inspected if needed repairs are to be found.
2. Awareness of needed repairs isn't enough to complete them. The maintenance department must be informed promptly of such needs through written authorization (job sheets, work orders, etc.).
3. Maintenance department must plan and complete its work promptly—in accordance with the best maintenance practices at minimum cost.
4. Completed work must be inspected by production and maintenance management for quality and completeness of workmanship.
5. Maintenance histories of all plant equipment must be developed and reviewed periodically to reveal where corrective measures or possible readjustments of inspection schedules are needed.

QUALITY CONTROL

"A New Philosophy of Electrical Component Acceptance" by H. G. Harding and R. A. Hulnick, INDUSTRIAL QUALITY CONTROL, *page 8, March 1959.*

Both vendor and consumer are guilty of contradictory component acceptance—accepting components initially rejected or vice versa. The authors point out that the solution to the problem of component acceptance lies in approaching the problem with a new philosophy by both vendor and consumer.

"Multi-Factor Experiments," by M. Zelen and W. S. Connor, INDUSTRIAL QUALITY CONTROL, *page 14, March 1959.*

When investigating the joint effect of several factors on the performance of a piece of equipment, on the yield of a product, or on the characteristics of a test method, a considerable advantage is gained if the experiment is conducted so that the effects of changing each variable can be evaluated jointly with the effects of changing the other variables. This article deals with the planning of such experiments.

"Top Management Decision Making," by J. F. Bourquin, INDUSTRY QUALITY CONTROL, *page 15, February 1959.*

This article treats the role quality activities can play in top management decision making. By eliminating expertise in statistical quality control, the author feels free to discuss this area from a management viewpoint, paying particular attention to the ways in which quality control can effectively help decision making at the highest management levels.

Cases are shown of how management direction can be helped through effective use of quality control in the four major aspects. These examples come from all the major portions of the total quality picture starting with design evaluations through processed and purchased material controls, quality audits and the sources of vital information through field service reporting.

WAGE INCENTIVES

"Honest-John Handling Incentives," by E. Seltzer, FACTORY MANAGEMENT AND MAINTENANCE, *page 192, January 1959.*

Honor is the key to successful materials handling incentives at the Exide Industrial Division. The plan has been working for two years for in-plant trucking and materials handling.

Incentives of this sort are uncommon. But the honor system feature of Exide's plan is almost unheard of. The idea is that each man keeps his own time record.

The plan has helped Exide boost the materials-handling work load by 10% and at the same time has resulted in reassignment of eight of the 40 men formerly needed for handling, shipping, and supply operations.

"Simpler Maintenance Incentive," by R. H. Tolman, FACTORY MANAGEMENT AND MAINTENANCE, *page 170, March 1959.*

This company's new incentive plan is based purely on past performance records as opposed to time study. It's designed to pay off on a 50-50 split for performance over 100%. Performance is measured on the basis of the time it takes to do a week's quota of jobs as compared with the historical standards. The more jobs the group does in less time, the better the bonus. The job standards are calculated en masse for each week after the work is done.

The principle of the plan is first to find the average time per job for all work falling into a series of job-time categories, namely 0-1.9 hours, 2.0-3.9 hours, 4-7.9 hours, 8-15.9 hours, 16-31.9 hours, 32-49.9 hours, and 50-up hours, then to find what percentage of all jobs done lies in each of these categories. There is no need to separate jobs by types or crafts.

WORK MEASUREMENT

"In Systems Analysis: What is Typical," by E. W. McNamara, THE OFFICE, *page 69, February 1959.*

Thorough clerical systems analysis frequently means an exacting study of volumes of clerical data to get facts such as, how many of a given document are processed in a day, a week or a month. After the number of units processed has been ascertained, the next step is to determine what constitutes a representative, or typical, specimen of the paper involved.

Clerical time values become important factors in the appraisal of the present method and in the recommended version of an improved method. If the analyst is not versed in work measurement, he must prepare himself to use time values, either by learning to use a stop watch, or by securing and learning to use standard time data. Using such standards, he at least is on the road to a fair comparison of methods. In applying time values he must learn the techniques of counting the number of carriage returns, measuring distances traveled by machine carriages, counting typewriter key-strokes, and many other elements or subdivisions of a clerical operation.

BOOKS

BEHAVIOR OF INDUSTRIAL WORK GROUPS: PREDICTION AND CONTROL, *by Leonard R. Sayles, John Wiley & Sons, Inc., New York, New York, 1958, 182 pages, $4.75.*

This is the first of a projected series of research studies conducted at Columbia's Graduate School of Business, on organizational behavior. The project is aimed at breaking down the traditional boundaries separating what are essentially interrelated fields: formal organization and administration theory, human relations and personnel management, management decision making and production management, and collective bargaining. In this initial report, the differences that exist between various work groups are discussed, and a method is offered for predetermining reactions of these groups to supervision.

INDUSTRIAL ELECTRONICS HANDBOOK, *edited by William D. Cockrell; 1408 pages, published by McGraw-Hill Book Co., 330 West 42nd St., New York 36, N.Y., $22.50.*

This handbook provides reference material on basic engineering and mathematics, physical laws, control elements, power supplies, control circuits, circuit applications, mechanical design, ultimate utilization requirements, and technical information sources.

Among subjects covered are computers, instrumentation, regulators, relays, transducers, amplifiers, and military and industrial utilizations. Mechanical design, testing, field installation, industry and customer preferences, and environmental requirements of electronic equipment are treated.

INTEGRATED COST CONTROL IN THE OFFICE, *by Frank M. Knox, McGraw-Hill, 330 West 42nd St., New York 36, 304 pages, $7.50.*

Techniques for reducing and controlling office costs are presented in this newest volume in the National Office Management series. Developed specifically for the office, rather than borrowed from factory techniques, these methods cover such factors as control over forms, methods and procedures; clerical work measurement, work simplification, and automation, record controls, etc. Each method has been tested and proved in actual use in businesses of varying sizes and kinds.

INTEGRATED PACKAGING AND MATERIALS HANDLING, *Management Report 21, American Management Association, 1515 Broadway, New York, 87 pages, $2.25 (AMA members, $1.25).*

This new AMA report presents three useful company studies describing the control of material movement through the planning and engineering of integrated packaging and materials handling systems.

Executives of Ford Motor Co. (Ford Div.) and Gerber Products Co. show how and why their packaging and materials handling systems are organized and operated.

Representatives of Lewis-Howe Co. indicate how they mechanized and integrated their packaging operations through "systemation."

This principle involves integrating machines into a self-regulating system by fashioning electrical and mechanical devices which will permit the product to perform the control function.

Materials handling and packaging personnel should find this report a valuable reference aid. Subject matter is based on material presented at AMA's 27th National Packaging Conference.

THE MOTIVATION, PRODUCTIVITY, AND SATISFACTION OF WORKERS, *by A. Zaleznik, C. R. Christensen, and F. J. Roethlisberger, Harvard University Graduate School of Business Administration, Boston 63, Massachusetts, 1958, 442 pages, $6.00.*

This is a report of a year-long, close-up study—made by three members of the faculty of the Harvard Business School—of the job experiences of fifty production workers. Clinical and statistical research methods were used. Of most interest to management are the last fifty pages, which discuss the findings, and suggest their practical implications for business.

For example, the authors conclude that workers whose subsistence needs are satisfied are no longer motivated by the traditional rewards held out by management. They state: "No amount of good wages, fringe benefits, and good working conditions, in and by themselves, will motivate such workers to give more than minimum effort." A new management approach to the solution of this problem is offered.

OFFICE MANAGEMENT: PRINCIPLES AND PRACTICES, *by John W. Neuner, South-Western Publishing Co., Cincinnati 27, 728 pages, $6.50.*

The fourth edition of this college text includes a section on office automation, and the rest of the book has been revised to bring the subject up to date. The author bases the core of this edition on human relations and cost reduction, but all office subjects are covered.

PURCHASING HANDBOOK, *edited by George W. Aljian, McGraw-Hill, 330 West 42nd St., New York 36, 1392 pages, $15.*

Prepared by a staff of 220 specialists to fully cover everything that will help purchasing personnel do the best job of getting the right commodity at the right price, time and place. Illustrations include 80 commonly used forms, many tables and charts, and examples of reports, manuals, contracts, letters, etc. There is also a glossary of terms and symbols.

THE ENGINEERING ECONOMIST, *a quarterly journal of the Engineering Economy Division of the American Society for Engineering Education, Box L, Stephens Institute of Technology, Hoboken, New Jersey, subscription rates $3.00 per year in the U. S. and Canada and $4.00 per year elsewhere.*

The journal presents the latest developments in Engineering Economics, Equipment Acquisition and Replacement Analysis, Capital Budgeting, Economic Evaluation, and related subjects, and also reviews of books and printed materials in these fields.

PROCEEDINGS OF THE TENTH ANNUAL NATIONAL CONFERENCE OF THE AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS, *held May 14, 15, and 16, at the Biltmore Hotel, Atlanta, Georgia, Case Bound Book, over 200 pages, price: $5.00, members; $7.00, non-members.*

Orders should be directed and checks made payable to Tenth National AIIE Conference, P. O. Box 5255, Station E, Atlanta 7, Georgia.

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PROFESSIONAL RELATIONS ACTIVITIES

An impressive list of accomplishments have been reported for this past year by the Committees of the Engineers Joint Council. These accomplishments represent the work of dedicated individuals, but they also reflect a strong interest on the part of member societies in EJC activities. The member societies have chosen carefully the individuals selected to represent them on these committees. Most of these men are leaders in industrial, professional, or academic fields and a group of this calibre should be expected to produce results that would reflect the highest credit on the engineering profession. In this respect they certainly have not failed. The 1958 Annual Report of the Engineers Joint Council stands as a testimonial of the work of these men. As a result EJC has become more firmly established as the agency of cooperation among the Engineering Societies. The impressive participation by industry in such matters as the 1958 salary survey indicates clearly the confidence and respect that have developed for EJC activities in this country.

Considering the fact that the AIIE has been a constituent member of the EJC for only one year we can note with justifiable pride that our participation has resulted in several important assignments to our representatives. This type of recognition is not lightly bestowed on fledgling organizations and attests among other things to the competence of our delegates and to the wisdom of the officers responsible for their appointment. A brief abstract of the work of these delegates can not adequately describe all of the problems that had to be faced nor the amount of time that had to be spent to carry out their missions. It is unfortunate that we must omit, for the moment, the other important committees in the EJC by restricting ourselves to a brief discussion of only those in which the AIIE participated. Such an omission at this time is certainly not because of a lack of interest on our part.

***Constitution and By-Laws*—(Delegate—H. Brock)**

A revision was made of the constitution and by-laws of the EJC in order to permit an application for a corporate charter under the laws of the state of New York. This application was granted on March 20, 1958, and on July 10, 1958, at a special meeting of the Board of Directors the Engineers Joint Council, Incorporated came into official being. Incorporation will facilitate the future operations of the Engineers Joint Council especially in matters of unity within the profession as well as from the point of view of tax requirements.

***Employment Conditions*—(Delegate—R. A. Engle)**

A study was made of the problems of compensation for civilian engineers in government service. As a result of this study the committee recommended that appropriate support should be given to legislation aimed at implementing the findings of the Cordiner Report on government employment practices. This recommendation was approved by the EJC Board of Directors on April 11, 1958.

A second survey was made by questionnaire of union activities on the campuses of engineering colleges. This survey confirmed the finding of the previous year that there is a rather ineffective exposure of students to unionization activities. However, where such exposure has been made there was little or no apparent effort to combat it on the part of the engineering profession.

***Engineering Manpower Commission*—(Delegates—H. Ashcroft, Jr. and C. H. Doolittle)**

A study was completed of engineering income from information gathered from approximately 700 employers of engineers. This study entitled *"Professional Income of Engineers—1958"* is probably the largest and most comprehensive study of this kind ever made in the United States.

A report was also completed in 1958 on the impact of government contracting procedures on the utilization of engineering manpower. The importance of this study is reflected in the fact that Department of Defense activities alone accounted for the employment of about 35% of the total number of engineers employed in the United States. (The recommendations of this sub-committee, with Herbert Ashcroft, Jr., Chief Delegate of AIIE, as Chairman, will be reported in this *Journal* as soon as it is made public).

During 1958 the Engineering Manpower Commission continued to keep an eye on the reorganization of the Reserve Forces provided for in the Reserve Forces Act of 1955. Hundreds of problems of young engineers with Military obligations were dealt with by this Commission. In conjunction with the Scientific Manpower Commission a document entitled *"Manpower Policy for National Security"* was prepared. Recommendations made in this document will undoubtedly be seriously considered by all organizations interested in manpower problems including the Executive and Legislative Branches of the government.

The EMC and the SMC continued publication of the "Manpower News Letter" which is distributed to over 12,000 individuals. In addition five articles on engineering manpower and related topics were published during the year in five national magazines.

***Engineers Joint Council Insignia*—(Delegate—Joseph Terr)**

A distinctive Insigne for EJC was selected by this Task Committee and adopted by the Board of Directors. The design chosen was submitted by Mr. Joseph Terr, AIIE.

***International Relations*—(Delegate—D. B. Porter)**

Much of this committee's business was concerned with the 5th UPADI Convention held in Montreal, Canada in September. (UPADI is the Pan-American organization of engineers of all principal nations of both Americas.)

Members of this group actively participated in the Canadian Sectional Meeting of the World Power Conference also held in Montreal in September. An impressive number of 1300 participants from 50 countries attended this meeting.

The Chairman and Secretary of the International Committee rendered assistance in connection with the 5th Conference on Large Dams held in New York City. Over 800 participants from some 50 countries attended this conference.

The EJC has been requested by the United States Department of State to assist in an in-plant training program in the United States for Philippine engineers. Work is underway on this project.

***Membership*—(Delegate—A. C. Seccia)**

During 1958 the AIIE was transferred from Associate to Constituent membership and the American Institute of Plant Engineers was confirmed for Associate membership. The Louisiana Engineering Society, the South Carolina Society of Engineers and the Consulting Engineers Council have been accepted as affiliate members. The total number of organizations in the EJC now

numbers 20 representatives and approximately three hundred thousand individual members.

***Planning Committee*—(Delegate—D. J. Olsen)**

This committee is charged with study of problems which affect long range developments in the engineering profession. Among these have been, during 1958, the investigation of the advantages which would follow closer relationships with federations similar to EJC but operating in other countries. The possibility of amalgamation of ECPD and EJC operations had been extensively explored within the Planning Committee before being placed before the EJC Board of Directors on January 16, 1959, which supported it unanimously.

***Practice of Engineering*—(Delegate—H. M. Owades)**

This committee continued to work on its assignment of developing a policy statement in regard to the practice of engineering by individuals, partnerships and cooperations. The committee has agreed that professional responsibility for engineering work is a personal responsibility which should be recognized as such by all laws relating to the registration of professional engineers.

***Recognition of Specialties in Engineering*—(Delegate—W. E. Alberts)**

The work of this group has been primarily in the area of improving communication for specialists in various branches of engineering. One proposal under study is the possible sale of publications of any society to the members of other organizations at member rates. Another idea under study is the possible inclusion in the "Engineer" of the table of contents of the technical publications of the member societies. Proposals such as these are being evaluated in terms of costs and procedures.

The work of the above committees, important as it is, is really only a beginning. The opportunities for the study of problems common to all engineers is unlimited. The benefits that will accrue to the individual engineer, to the engineering profession and the nation at large are sufficient incentive to warrant our continued support of EJC activities.

Reported for the Professional Relations Committee
BY O. J. FEORENE

CALENDAR

June 22-July 3: Special Summer Session at Massachusetts Institute of Technology in Applications of Probability Theory to Operations Research. Tuition, $275. Write: Professor James M. Austin, Director of the Summer Session, Massachusetts Institute of Technology, Cambridge 39, Massachusetts.

August 17-28: Special Summer Session at Massachusetts Institute of Technology in Industrial Dynamics. Tuition, $325. Write: Professor James M. Austin, Director of the Summer Session, Massachusetts Institute of Technology, Cambridge 39, Massachusetts.

August 17-28: Fourth Annual Course in Modern Industrial Spectroscopy; Arizona State University. Write Dr. Jacob Fuchs, Director, Modern Industrial Spectroscopy, Arizona State University, Tempe, Arizona.

August 24-28: Industrial Engineering Conference; University of Michigan. Write Engineering Summer Conferences, Summer 1959 Program, University of Michigan, Ann Arbor, Michigan.

PERSONALITIES

PHIL CARROLL

The Northern New Jersey Chapter of the Society for Advancement of Management presented Phil Carroll with the Distinguished Service Award at special ceremonies on Thursday, February 19, at the Hotel Suburban in East Orange. We all join in extending congratulations to Phil, who is National President of SAM as well as a valued member of AIIE.

EARL MARTINSON

Earl P. Martinson, for the past ten years, Head Professor of Industrial Engineering at the University of Florida, at Gainesville, has resigned his administrative duties as head of the department in order to return to full-time teaching and research.

During these years, he has been an active member of AIIE, serving as Regional Vice President for one term. He has been instrumental in starting the student chapter at the University as well as having had an active part in the formation of five senior chapters.

EMMA B. DONNELLY

Since November, 1956, the *Journal of Industrial Engineering* has been fortunate to have as its part-time secretary, Mrs. Emma Burgess Donnelly. The *Journal* staff has enjoyed the pleasant association with Mrs. Donnelly because in all phases of her work she has displayed enthusiasm, efficiency and interest. She is particularly good at executing in a responsible manner the editorial changes and corrections. In addition she is very proficient in answering correspondence, sending out articles for review, and many other detailed tasks that are important to publishing the *Journal*.

Her abilities and resourcefulness are not surprising in view of her educational background and experience. She was valedictorian of her graduating class at Good Hope High School, and after completing a business course, she was employed by the Farmers Bank, Monroe, Georgia, for more than five years. Upon entering the United States Navy as a WAVE she attended yeoman training school at Oklahoma A. & M. College, and was later assigned

EMMA B. DONNELLY

to the Naval Air Station, Miami, Florida. While in service she met Bill Donnelly and they were married in 1945. Bill is now employed by the Firestone Tire and Rubber Company.

Her services to the *Journal* are part-time since she also has a career as mother to Mike, age 13, and Ann, age 10. The Donnellys make their home in Decatur, Georgia.

AKRON CHAPTER

The February meeting of the Akron Chapter featured a lively round table discussion concerning the topic, "Is Industrial Engineering a Profession?" Professor Michael Bezbatchenko of Akron University was moderator, and Dean R. D. Landon of Akron University summarized the ideas expressed and offered constructive advice for all engineers seeking professional status.

A tour of the Chrysler Stamping Plant of Twinsburg, Ohio, was held on April 8, when our members observed and discussed the current Industrial Engineering problems of the automotive industry.

Our program committee has already started planning next year's events. Dr. N. Auburn, president of Akron University, will address the October meeting upon his return from Russia. His topic will be "The Russian Educational Threat."

CENTRAL ARKANSAS CHAPTER

The Central Arkansas Chapter of AIIE received its charter from Southwest Region Vice-president J. T. Elrod on May 16, 1958, at a meeting held in Little Rock, Arkansas. Thirty members and guests attended. Mr. William Ewald of the Arkansas Industrial Development Commission and Prof. John L. Imhoff of the University of Arkansas also spoke to the group.

Chapter officers were elected for the next year as follows: President: John L. Imhoff, University of Arkansas; Vice-president: Merrill W. Seeley, Hoerner Boxes, Inc.; Secretary: Wray Wilkes, University of Arkansas; Treasurer: M. N. Cavendor, Westinghouse Electric Corp.; Directors: W. J. Hamilton, Westinghouse Electric Corp.; J. J. Brennan, Baldwin Piano Co.; R. J. Eastman, Clary Corp.; Ben W. Hopkins, Industrial Engr. Associates.

The June meeting featured a discussion of "Modern Industrial Engineering Practice" by Hugh Dennett, Assistant Prof. of IE, and Palmer Terrell, Instructor in IE, both of the University of Arkansas. A question and answer period followed the discussion.

The chapter's first annual family picnic was held on Aug. 16, 1958, at Lake Nixon near Little Rock.

The Fall series of activities got under way on Oct. 4 with a lunch meeting in Little Rock. Plans for the year's programs and projects were discussed. A talk on "Data Processing" was given by Wray Wilkes, Associate Prof. of IE, University of Arkansas.

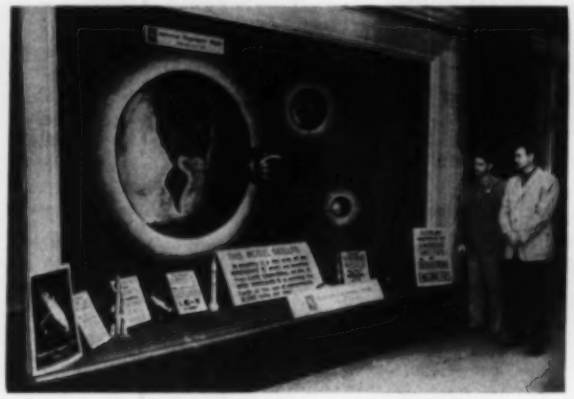
On Nov. 14, a joint meeting was held in Fayetteville, Ark., with the Univ. of Arkansas Student Chapter. A panel consisting of University graduate Industrial Engineers, Kerwin Ashford, Frank Carl, Vernon McBryde, Chester Phillips, and Larry Stephens, discussed "The Industrial Engineer in Industry." Following the panel, Mr. Tom Schiewetz, Manager of the Fayetteville plant, Standard Register Co., gave "Management's View of IE." Members of both senior and student chapters then became better acquainted during a "coffee-and-doughnut" hour.

The Dec. 12 meeting was held at Little Rock amid ice and snow. The subject of the program was "Contract Negotiating" featuring a talk by E. O. Crandall of the Stuttgart Works of Fairbanks-Morse Co. and a movie entitled "You Are There at the Bargaining Table."

Programs for the next eight meetings have already been planned and a good year in 1959 is expected by all in the Central Arkansas Chapter.

CHATTANOOGA CHAPTER

The Chapter and the University of Chattanooga co-sponsored a one day conference at the University, February 13, 1959. The Conference theme was "Cost Reduction Through Work Measurement." Applications of time study, pre-determined times, work sampling, photography, and work simplification were discussed. Separate sessions were available for supervisory personnel and Industrial Engineers. The Conference was attended by one hundred and fifty-eight, was well received by all, and was a financial success for the Chapter and University.



The Chapter participated with other Engineering Societies in the city, sponsoring Engineers Week. The picture shows our window display which was the first place winner in the local contest.

LOUISVILLE CHAPTER

At our special "Ladies Night" meeting in December, Dr. Harvey Hahn of the Speaker Bureau of General Motors Public Relations Department was our featured guest. Dr. Hahn, who is also a minister, provided delightful entertainment with his homey style of story telling which was reminiscent of that of Sam Levenson, T.V. personality. Many of the wives who attended this meeting expressed a desire for more of these non-technical "Ladies Night" meetings.

Mr. Edward Thoben, Supervisor of Industrial Engineering for the American Radiator and Standard Sanitary Corporation, was the guest speaker at our January meeting. Mr. Thoben presented his topic, "Job Evaluation," most effectively. He used several visual aids in chart form to illustrate his speech.

For our meeting in February, Mr. William S. Wright, Supervisor of Office Incentives of the Eli Lilly Co. in Indianapolis, spoke to us on the subject of "Office Incentives." This meeting took place in the new University Center Cafeteria on the University of Louisville campus.

Our speaker for the March meeting was Keith Boaz of The Institute of Modern Management. He spoke to us most interestingly on the topic, "New Developments in Direct Labor."

MEMPHIS CHAPTER

Our speaker for the January meeting was Mr. R. S. Matheson, Manager of the Methods Department in the mail order division of Sears, Roebuck & Co., in Memphis. He described to us the problems and solutions in the development of the layout and work flow in the basement floor catalog order activity of the Sears Crosstown store. This behind the scenes story of the catalog sales operations was both enlightening and interesting.

Our February meeting was a Ladies Night Dinner held at the

Holiday Inn. Mr. Morris Patterson of Kimberly-Clark Corp. conducted a Brainstorming Session on "Household Problems" which proved to be of particular interest to the ladies. The Chapter presented a corsage to each lady present, and a dress was given as a door prize.

METROPOLITAN NEW JERSEY CHAPTER

Robert T. Walls, Chief Industrial Engineer with Propeller Division of Curtiss-Wright Corporation, was featured speaker at the February meeting. "Direct Labor Cost Control Tools" was the subject of his address. The talk was built around a "Vu-Graph" presentation involving approximately 25 slides. Members of the chapter greatly benefitted from hearing of Mr. Wall's labor cost control experiences.

The guest speaker at the March 25th meeting was Roger I. Wilkinson, Traffic Studies Engineer at Bell Telephone Laboratories in New York. His subject was, "Some Engineering Aspects of Queueing Theory." Mr. Wilkinson traced the early mathematical studies of delays, and gave some of the most useful formulae for solving problems of this kind. He described how delay time varies when service demands are satisfied in random order, as against a first-come, first-served order.

Before the meeting, the guest speaker joined a group of chapter officers, members, and guests at an informal dinner in the Hotel Suburban dining room.

Remember the 12th Annual Conference slogan—'61 in '61.

MIDDLE TENNESSEE CHAPTER

Wallace Clark, director of management research for General Shoe Corp., spoke at the January dinner meeting of the Middle Tennessee Chapter, AIIE. Mr. Clark, who has degrees in law and administration from the University of Chicago, was previously a United Nations consultant on organization and administration in China. Before he joined the UN, he was deputy director of the Illinois State Welfare Department.

NORTHEASTERN REGION

Chapter presidents and other officers of twenty-three of the twenty-five chapters in the Northeast Region met at the Suburban Golf Club in Union, N.J., on Saturday, January 24, 1959. The meeting was presided over by Mr. William J. Vallette, Vice President, Northeastern Region, AIIE.

Among the business items transacted at the meeting were preparations for the 1959 Regional Conference to be held at Philadelphia on November 5, 6, and 7, 1959. Many other items concerning chapter operations, programs, membership, etc., were discussed.

Dr. Alex Rathe, Chairman of the AIIE Professional Relations Committee, and Mr. Henry Owades, National Director for UET affairs also spoke. Arrangements for the meeting were handled by Mr. Vincent Cavanaugh, N.J. Chapter Secretary.

OKLAHOMA CITY CHAPTER

Oklahoma City Chapter sponsored an all day personal development clinic and workshop on January 24th featuring Ray Montsalvatge of Dayton, Ohio. Montsalvatge is the former Director of Field Education for the National Management Association and is currently retained by the University of Puerto Rico to assist in a program designed to greatly expand the school's extension service.

Sixty Industrial Engineers from Kansas, Oklahoma, and Texas attended the session which emphasized personality development, applied psychology, personal planning, and memory training.

Mr. George H. Scott, Personnel Manager for Chance Vought Aircraft Corp. of Dallas, Texas was luncheon speaker.

The March meeting of the chapter was a combined meeting with the Tulsa and Wichita chapter and the Oklahoma State University student chapter on the campus of OSU at Stillwater, Oklahoma. Principal speaker was Dr. Clark Dunn, National President of the National Society of Professional Engineers.

OKLAHOMA CITY CHAPTER PERSONAL DEVELOPMENT CLINIC, RAY MONTSALVATGE SPEAKER.

ST. LOUIS CHAPTER

We were extremely proud to have Mr. G. H. Gustat, National President of AIIE, with us for our February meeting. Mr. Gustat, who is Chief Industrial Engineer of Eastman Kodak Company, Rochester, N.Y., conducted a conference-type meeting with time for quizzing and discussion. It was an outstanding opportunity for our chapter to gain direct, first-hand access to information concerning all the varied aspects of the National Organization of AIIE.

In place of our regular March meeting, the chapter sponsored a one-day Work Measurement Conference dealing with "Work Analysis Through Movies." We were especially fortunate to have as luncheon speaker Walter Wiesman, who came to this country with Dr. Werner Von Braun in the days of the V-2 missile, and is now the technical expert at Red Stone Arsenal. He spoke on "The Engineer—Manager in the Space Age," and backed up his talk with some recent films of "space probes." Wiesman also is Command Advisor to the Personnel Director of the U.S. Army Ballistic Missile Agency.

FUNCTIONS AND BASES OF TIME STANDARDS

By H. O. Davidson

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Research Abstracts

July 1947 — July 1957

The following research abstracts represent a partial listing of research related to Industrial Engineering that was performed primarily during the July, 1947 to July, 1952 period as well as additional abstracts for the July, 1952 to July, 1957 period not previously published. This information was organized by the AIIE Research Information Committee from material furnished by various organizations conducting research. It does not represent an exhaustive listing, for not all research has been reported. Additional abstracts will be reported at a later date. Plans are being made to obtain and publish additional abstracts for the period currently being reported and for current research on a yearly basis.

The Research Information Committee has made no attempt to judge the merits of any research report. It has collected, eliminated "application" articles, and classified the reports according to the categories used by the AIIE Director of Research and the Research Committees. Reports were considered to be "application" when existing theory and/or technology was utilized to solve a specific problem without advancing a new or unique and generally applicable concept, theory, hypothesis or technique. The classification categories of each report are indicated at the start of each listing. These categories are:

1. WORK MEASUREMENT
2. METHODS
3. PLANT ENGINEERING AND DESIGN
4. HUMAN ENGINEERING
5. ENGINEERING ECONOMICS
6. ORGANIZATION PLANNING
7. INDUSTRIAL STATISTICS
8. PRODUCTION CONTROL
9. DATA PROCESSING SYSTEMS DESIGN
10. OPERATIONS RESEARCH AND SYSTEMS DESIGN
11. COSTS AND COST CONTROL
12. INDUSTRIAL ENGINEERING EDUCATION

Copies of original research reports may be obtained by contacting directly the author or place mentioned in the abstract. Masters and doctorate theses are usually available on inter-library loan, but printed copies are not usually available. Some university libraries have facilities for supplying photostat or microfilm copies in lieu of inter-library loans, for those desiring them.

The Committee wishes to thank the organizations that have helped with this project, and to encourage the participation of all organizations in the extension of the project. Information should be sent to:

AIIE Research Information Committee
Department of Industrial Engineering
Washington University
St. Louis 5, Missouri
U.S.A.

Reno Cole *W. R. Hudson* *Jay Goldman, Chairman*
Jack CoVan *Robert F. Miller*
Daniel Duffy *Robert J. Wimmert*

1. WORK MEASUREMENT. *(Procedures Preparatory to Work Measurement, Timing, Measuring Operator Performance, Measuring Job Difficulty, Delay Allowances, Machine Control and Interference Allowances, Personal Allowances and Fatigue, Basic Motion Standard Data, Elemental Standard Data, Control of Standard Times, Special Labor Category Standard Times, Work Sampling.)*

1,2. An Analysis of Basic Motion Timestudy; *Carl Carruth; M.S. Thesis, August 1956; University of Houston, Cullen Boulevard, Houston 4, Texas.*

Laboratory experimentation was undertaken to reproduce and verify basic motion timestudy data as developed by J. D. Woods and Gordon and published in the Basic Motion Timestudy Manual. Micromotion analyses as well as time records obtained by a special recording device were produced experimentally. These data were analyzed statistically using correlation, analysis of variance, and other methods.

1. An Analysis of Current-Practice, Unaided, Time-Study Ratings; *Arthur J. Ela; M.S. Thesis, June, 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Data on Current-Practice time-study ratings were gathered and analyzed as to consistency, accuracy, and amount of variation. As a result, it was felt that the present state of time-study rating is not up to the level required for its wide spread acceptance and use with confidence.

1,2,4. An Analysis of Some Differences between One and Two-Handed Industrial Work; *Eric Ischinger, Jr.; M.S. Thesis, June, 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This study was made to determine a correct value for the secondary adjustment for bimanualness, which was a 10% allowance at the time this research was done, it was concluded that a value of 18% is more nearly the correct adjustment to be applied for bimanualness.

1,2,3,4,5,8,11. An Analysis of the Suitability of the Work Unit Approach for the Woodworking Industries; *Herman F. Hess, Jr.; M.S. Thesis, January, 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This thesis introduces a set of work units for the woodworking industry. A new method of attacking the production planning problems, time and motion study problems, comparison of machinery problems, cost comparison problems, and employee training problems is presented by this work unit approach.

1,4. The Applicability of Six Standard Tests in the Prediction of Time Study Rating Ability; *Willis G. Holder; M.S. Thesis, August, 1949; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This study was made to determine if there was any relationship between time study rating ability and performance on a group of standard test criteria. It was concluded that in so far as the experimentation has gone there is no indication of a relationship between the two.

1. The Application of Allowances to Time Standards; *A. J. Rowe; Research Report 40, March, 1954; Management Sciences Research Project, University of California, Los Angeles 24, California.*

The use of sampling has improved the estimates of allowances.

Where allowances are not properly applied, they may lead to error and inconsistencies. This paper discusses the possible errors and methods of correction.

1,10. Application of Queueing Theory to Receiving Docks; *LeRoy A. Wickstrom; M.S. Thesis, June, 1957; Librarian, Illinois Institute of Technology, Chicago 16, Illinois. (Non-technical synopsis has been submitted for publication to* **Factory Management and Maintenance.**)

This paper is an example of using waiting line theory in work measurement and facility planning. A cost model is developed to show the effect of the number of crews, amount of work, production standards, efficiency and number of men. An analytic method of computing delay allowances is suggested. The need for controlling the availability of extra work in random input systems is stressed.

1,8,11. A Case Study in Newspaper Operations; *Sidney Davidson and Robert H. Roy; Research Project, 1959; American Newspaper Publishers Assn. Research Institute, 140 South Dearborn Street, Chicago 3, Illinois. (To be published in* **Operations Research and Systems Engineering,** *the Johns Hopkins Press.)*

The report describes studies of the composition of local display advertising in newspapers. Analysis has developed a three-variable model which predicts composition time with considerable accuracy and is useful in demand analysis, in the measurement of productivity and department efficiency, and in cost accounting by individual ads, by accounts, and by classes of advertising. The nature of composition of local display for job cost is not economically feasible. The model makes this possible.

1,2. A Checklist for the Therblig Hold; *Eugene T. Kirk; M.S. Thesis, June, 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The purpose of this study is to attempt to develop a check list which will facilitate a systematic approach to the problems of selecting or designing devices to eliminate the therblig hold. A survey of texts and periodicals established basic principles which were used as a guide in developing the check list.

1. Comparison and Evaluation of Three Time Study Rating Techniques; *Andrew P. Radkins, M.S. Thesis, June, 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Two new techniques, single-image aid and multi-image aid rating, used by 73 midwest Industrial Engineers, were compared and evaluated along with the standard on-the-job rating technique. The group as a whole, on the basis of accuracy and consistency, was able to rate 18 paces just as effectively using the two entirely new techniques as when using their own conventional techniques.

1,4. A Comparison of British and American Human Work Tempos; *C. E. Nelson; M.S. Thesis, June, 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Films taken for British observers were used to compare British and American concepts as to what is a performable day's work for the typical worker. Based on this comparison, it was concluded that there is no significant difference in British and American human work tempos.

1. A Comparison of Rating Methods for Time Study; *Harry O. Rohde; M.S. Thesis, June, 1952; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

A comparison was made of the results obtained through the use of four rating methods with established correct base times for a sample job. The data obtained were analyzed on the basis of accuracy and consistency of results. Four main conclusions were drawn.

1. A Comparison of Two Methods of Presentation for Time Study Rating; *Louis Margolin; M.S. Thesis, June, 1948; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This thesis compares time study ratings obtained from operator performances directly with ratings from motion pictures. The results showed that, under the experimental conditions, the motion pictures were rated more consistently and accurately than the actual operator, both by element and by cycle.

1. Design of a Timing Device for Time Study; *Willis H. Hard; M.S. Thesis, January, 1942; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This thesis discusses the development of a design for a new type of timing device to be used in the factory for time study applications. A working model was placed in industry to check the functional characteristics of the device and was found to be satisfactory.

1,4. The Determination by Means of Metabolic Measurements of the Time Allowances to be Included Within Standard Rates for Jobs Partially Controlled by Machines; *J. F. Wood; M.S. Thesis, June, 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

An attempt is made to correlate a worker's oxygen consumption with machine controlled work cycles.

1. Development and Evaluation of a Pace Scale for Time Study Rating; *Robert N. Lehrer; Ph.D. Thesis, June, 1949; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Proposal of and development of pace scale for use as a standard in time study investigations.

1,10. Development of Process Control Elemental Parameters for Standard Data Utilizing Statistical Techniques; *Owen W. Miller M.S. Thesis, September, 1958; Engineering School Librarian, Washington University, St. Louis 5, Missouri.*

Comparison between the ordinary standard data method and the multiple regression analysis method to develop standard data for grinding gray iron castings with a portable grinder. The multiple regression equation developed gives significantly better answers than the ordinary standard data method.

1,11. Economic Factors Applied to the Operation of Automatic Screw Machines; *Thomas J. Schimmels; M.S. Thesis, June, 1956; School of Mechanical Engineering, University of Wisconsin, Madison, Wisconsin.*

This thesis deals with finding the most economical and practical number of automatic screw machines to be run by one operator. It employs various methods of calculation and experimentation to develop the interference factors. Interference, machine efficiency, and labor and burden rates are combined to establish the point of lowest piece cost.

1,2. Effect of Introduction of an Element of Work in the Original Cycle of Therblig, Motion Path, and Time; *Donald H. Denholm; M.S. Thesis, January, 1952; Librarian, Washington University, Engineering Library, St. Louis 5, Missouri.*

Experiments to determine the effect on hand movements when new element or/and a mechanical variation is introduced into the original job. Results show that: 1. the total time and distance moved vary when the sequence of therbligs or the work conditions change; 2. most therblig times will vary when the work conditions change, and will depend upon the location of the therbligs in each cycle; and 3. the motion pattern and the area under the motion's path vary when the hand moves to and from the object.

1,2,4. Effect of Lever Size upon Time Required to Operate; *Antonio A. A. Caminada; M.S. Thesis, June, 1952; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Analyses of operations performed by ten student operators showed that the time required to operate levers was closely proportional to torque and distance traveled by the hand. The path the hand has to follow is probably the predominant factor determining the time for operation.

1,2. Effect of Operator Pace on Work Sampling Results; *Albert B. Drui; M.S. Thesis, September, 1957; Librarian, Engineering Library, Washington University, St. Louis 5, Missouri.*

A study of the effect of an operator's pace on work sampling results. A total of about 13,000 observations was made for four different jobs, each consisting of 6 to 9 elements, performed by groups of operators. Some conclusions: 1. Pace does not affect percent occurrence on highly repetitive elements but does when methods are not standardized; 2. non-incentive clerical work is not as adaptable to the work sampling technique as incentive paid factory work; and 3. repetitive elements give greater spread in pace than non-repetitive elements do.

1,2,4. Effect of Pace and Distance on Energy Expenditure, Body Member Acceleration, and Motion Patterns, for Transport Empty; *Jack E. Eskilson; M.S. Thesis, June, 1952; Librarian, Engineering Library, Washington University, St. Louis 5, Missouri.*

A study of the relationship among 1. the energy expended, 2. the motion patterns and the distance moved, and 3. the rate of activity. Experimental results show that: 1. When both pace and distance are increased, the energy expended, the acceleration, and the constant velocity increase. 2. The deceleration increases significantly as pace increases but not significant as distance increases. 3. The percent of time spent in deceleration increases as the distance increases (not affected by pace).

1,2. Effect of Visually-Restricted Grasp on Two-Hand Work Cycles; *Rakhal D. Sahz; M.S. Thesis, May, 1958; Industrial Engineering Division, Mechanical Engineering Department, University of Minnesota, Minneapolis 14, Minnesota.*

Variations in cycle time and element time, caused by restricting the subjects' view of the grasping point, were studied, using jumbled pegs in pans at different locations and with one-hand and two-hand cycles. Data were recorded automatically on SEMTAR an electronic motion timer. Cycle time increased 8% to 19% for blind grasp over visually-aided grasp, depending upon location of supply pans and number of hands used. The change to a blind grasp significantly increased both grasp and insert time, but reduced reach and move times.

1,2,4. Effects of Visual Requirements upon Certain Simultaneous Hand Motions; *Stanley M. Block; Ph.D. Thesis, July, 1956; Library, University of Minnesota, Minneapolis 14, Minnesota.*

The objective was to determine the changes in cycle and element times caused by variations in the location and grasping-orientation (uniform vs. jumbled) of pegs, considering both one-hand and two-hand cycles. It was found that the optimal grasping location varied and is dependent both upon bio-mechanical and visual-requirement considerations. It was also found that the percentage increase in cycle time with two-hand cycles depends upon the complexity of the cycle elements.

1. An Evaluation of a Single Standard, Single Image Rating Aid for Time Study Rating; *Wilbur Gordon Sherwood; M.S. Thesis, June, 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The single loop aid tends to eliminate any possible difference in accuracy and consistency by raters due to degree of time study experience, type of time study training, number of plant employees, method of rating, size of town in which company is situated, or geographical area.

1,4. An Evaluation of the Effectiveness of Retention of the Concept of a Standard Embodied in a Multi-Image Pace Rating Loop; *Anthony Tai Tseng; M.S. Thesis, August, 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

A method to make the multi-image pace rating loop more effective is to train the users through controlled practice in the use of the loop. A training program was designed, administered, and conclusions drawn.

1. An Evaluation of the Mundel Multi-Image Rating Loop; *Frank Ronald Greenberger; M.S. Thesis, June, 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Results of an experiment which was designed to evaluate a multi-image time study cycle loop are reported. The judgment of the observer upon the completed time study was the center of attention. Ratings were made by people working in the field of time study. Factors such as years of experience, education, training, and size of plants in which time study observers work were considered and compared with the results.

1. An Evaluation of Time Study Ratings of a Synthetic Task; *Lawrence Stephen Lockett; M.S. Thesis, June, 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The use of synthetic tasks to test the consistency of time study ratings.

1. Fair Day's Work Ratings; *C. Sellie and E. Maloney; July, 1955; Standards Engineering Company, 919 North Michigan Avenue, Chicago 11, Illinois.*

Statistical review of film ratings by 125 engineers of 10 operations. Analysis of variation by incentive experience, and years of time-study.

1. Group Evaluation of the Accuracy of a Set of Time Standards; *Joseph H. Earnest Jr.; M.S. Thesis, June 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The time study ratings of a company were evaluated and compared to the ratings of other engineers with regard to any difference of standards between the two. The study showed that no appreciable difference was evident between the concept of standards of the work session engineers and the company.

1. History of Predetermined Time System; *C. N. Sellie; July, 1956; Standards Engineering Company, 919 North Michigan Avenue, Chicago 11, Illinois.*

Tracing start of systems, influencing sources, and classifying systems into three basically different types of Predetermined Type Systems. Describing the three major types and explaining differences.

1. Instrumentation for Measurement of Fundamental Motion Times; *Frank W. Tippitt; M.S. Thesis, April, 1958; Librarian, University of Houston, Cullen Boulevard, Houston 4, Texas.*

A study of the functional needs of a precise and accurate method of measuring fundamental motion times is made, and the general specifications of a specific system involving electronic timers and printing recorders are presented. In addition to the design of the system, data are presented showing its performance, including standard error and accuracy.

1,7. An Investigation of Methods for Determining the Number of Observations in a Time Study; *De Young and Ted Orville;*

M.S. Thesis, August 1957; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.

The assumption of normality for a time study data population was tested and found to be true. Five methods for determining the number of cycles in a time study were examined and compared. Experiments were conducted with each of the five methods. Conclusions were that two of the methods were unsatisfactory due to poor accuracy, and one was undesirable because of the great number of observations it required.

1. Investigation of the Effect of the Amount of Body Used on the Accuracy and Consistency of Pace-Rating (Multi-Image Loop); *Flavio Monteiro; M.S. Thesis, June, 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Different jobs involving different body members were filmed at different paces and raters were asked to pace-rate them, first unaided, and secondly aided by the multi-image loop. It was concluded that, except in the case of the walking job, the loop helped the raters considerably in improving their accuracy, even when it did not improve their consistency.

1. An Investigation of the Effects of Machine Time on Operator Pace; *Robert Warren Llewellyn; M.S. Thesis, June, 1948; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

An evaluation of operator pace as influenced by the percent of cycle time controlled by a machine.

1. An Investigation of the Optimum Number of Images on a Multi-Image Loop; *Joe Lockett Craig; M.S. Thesis, August, 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Several subjects rated motion pictures of jobs with the aid of three multi-image loops of six, nine and twelve images. It was concluded that the number of images had no significant effect on pace rating or consistency of pace rating, and the optimum number of images on a multi-image loop must depend on the use to be made of the loop.

1,2,4. An Investigation of the Suitability of the Sandborn Eis Metabolism Tester to Basic Motion Study Experimentation; *Seymour Tilles; M.S. Thesis, June, 1949; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

A study was made of five subjects performing three simple tasks involving 1. full arm motion, 2. forearm motion, 3. wrist motion. It was found that for both the full arm and the forearm tasks the metabolism tester gave a significant variation in oxygen consumption. The wrist task, however, proved to be too small to yield results which were statistically valid.

1,2. An Investigation to Determine the Próportionality of Elemental and Therblig Times at Typical Levels of Factory Activity; *Peter Walz Schwab, Jr.; M.S. Thesis, February, 1948; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The object of study was to determine the degree of correlation between therblig time and rate of activity, and also between various elements of a given job and changes of pace.

1,10. Machine Interference for the Case of One Repairman, Random Downs, and Constant Repair Time; *Gordon R. Antelman; M.S. Thesis, April 1958; Industrial Engineering Division, University of Minnesota, Minneapolis 14, Minnesota.*

General formulas are derived in this report for closely approximating the probabilities of waiting lines of all possible sizes for systems of from two to five machines, under the assumption of a single repairman, Poisson input, and constant holding times.

1. The Nature of Stopwatch Study Errors among Experienced Industrial Engineers; *Irwin Philip Lazarus; M.S. Thesis, February, 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

A report on the size of mean error and standard deviation on a study of fifty experienced Industrial Engineers using stop watches. Includes comparison of continuous and snap back methods of watch reading.

1,12. The Present State of Time Study; *Bernard S. Borrus; M.S. Thesis, February 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

A questionnaire (70 questions), presented to 73 time study men, was analyzed and explained with a view toward clearing up, for industry, misconceptions about time study. Emphasis was placed on questions of educational background and time study training, and on better understanding of time study principles and techniques.

1,2,4. A Proposed Technique of Motion Analysis for the Measurement of the Relative Skill Requirements Inherent in Repetitive Industrial Operations; *Dennis Ivor Solomon; M.S. Thesis, June, 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Methods were developed for the quantitative measurement of manual dexterity, muscular coordination, eye and hand coordination, and learning time as they relate to repetitious job performance.

1,7. Random Ratio-Delay; *G. E. McAlister; M.S. Thesis, April, 1953; Management Sciences Research Project, University of California, Los Angeles 24, California.*

The application of the statistical theory of random sampling to ratio-delay or work sampling. A description of how to design the sampling procedure, and analyze the results.

1,7. Relative vs. Absolute Errors in Delay Measurement; *A. J. Rowe; Research Report 24, October 1953; Management Sciences Research Project, University of California, Los Angeles 24, California.*

A method is proposed for choosing an optimal sample size for work sampling. The method is a joint function of statistical theory and the accuracy of time standards.

1. Simo Allowances in Predetermined Times; *C. N. Sellie; January 1957; Standards Engineering Company, 919 North Michigan Avenue, Chicago 11, Illinois.*

Evaluation of simo allowances by RCA, General Electric, and Westinghouse systems as reflected in Work-Factor, Motion-Time-Systems, and Methods-Time-Measurement.

1,10. A Statistical Model for Time Study; *H. P. Edmundson and R. T. Nelson; Research Report 36, January, 1955; Management Sciences Research Project, University of California, Los Angeles 24, California. (Also see* **Journal of Industrial Engineering,** *May-June 1955.)*

A discussion of the basic concepts underlying methodology and the proposal of a new statistical model as a sound basis for estimating standard time.

1,4. A Study of the Relationship between Time Study Rating Ability and Certain Psychological Tests; *Frank L. Seeger; M.S. Thesis, January, 1951; Engineering Library, Washington University, St. Louis 5, Missouri.*

A study of the relationship between time study rating ability and the test of practical judgment, the Kuder Performance Record, and the Bernreuter Personality Inventory. Results indicate that the predictability of rating ability by the above tests is not yet ascertainable.

1. A System of Predetermined Work Times; *Irwin Philip Lazarus; Ph.D. Thesis, June, 1952; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Proposal of system of predetermined work times for approximation of standard job times in 1. scheduling product flow; 2. estimating labor and machine costs; 3. balancing operation times in assembly lines; 4. comparison of job methods and 5. prediction of time required for skilled tasks using unskilled workers.

1,2,4. Time and Energy Efforts Involving a Turn and a Movement Treated Separately and Combined; *Charles C. Pohle; M.S. Thesis, June, 1952; Engineering Library, Washington University, St. Louis 5, Missouri.*

An investigation of the energy and time relationships of two basic motions, turn and movement, and their combination. Significant differences were found between the time to perform a combination turn and movement and; 1. the time to turn; and 2. the time to move. No significant difference was found between the combination and the movement itself when compared on the basis of oxygen consumed per cycle.

1,2. Time Differences and Motion Pattern Changes as the Result of a Mechanical Variation in a Cycle; *Joseph W. Wilkes; M.S. Thesis, January, 1951; Engineering Library, Washington University, St. Louis 5, Missouri.*

An investigation of the dependence and relationship among body member movements when work differences are introduced in one therblig of each type of activity. Experimental results show that a change in work conditions in one therblig in a sequence of therbligs 1. affects significantly the time of the total sequence and the time of each therblig and, 2. causes different motion patterns and different actual distance moved for each work condition.

1. Who Threw the Monkey-Wrench in Mr. Tippett's Theory; *G. E. McAllister and R. T. Nelson; Research Report 3, 1953; Management Sciences Research Project, University of California, Los Angeles 24, California.*

A discussion of independence and recording of long delays in ratio delays or work sampling studies.

1,7. The Work Sampling Technique; *A. J. Rowe; Research Report 11, February 1953; Management Sciences Research Project, University of California, Los Angeles 24, California.*

A presentation of the theory and methodology in the application of sampling to the measurement of industrial activities, including work delays.

2. METHODS. *(Non-repetitive Work Analysis Techniques, Repetitive Work Analysis Techniques, Basic Principles Investigation, Evaluation Procedures, Testing Procedures, Installation Procedures.)*

2,4. Analysis of Variation of Human Energy Consumption with Length of Movement under Equal Pace; *James E. Hoover; M.S. Thesis, August, 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The operation studied was a horizontal arm movement of lengths five, ten and fifteen inches using three different paces. The results showed that energy expenditure under equal pace was definitely not a function of length, but that pace exerted a significant effect upon this expenditure.

2,3. Apple Sorting Methods and Equipment; *D. Loyd Hunter, Francis Kafer, and Charles H. Meyer; Marketing Research Report 230, August, 1958, U. S. Department of Agriculture, Transportation & Facilities Branch, MRD, AMS, Washington 25, D.C.*

A study of methods and equipment used for sorting apples in the Pacific Northwest. After evaluating existing methods, the objective of this study was to develop and test new sorting methods, devices for existing equipment, and to develop and test a new sorting table. Improvements in existing equipment, such as installing lanes and cull chutes, significantly increased sorting efficiency. A new "float-roll" sorting table was developed which further increased sorting efficiency.

2,4. Determination of the Optimum Angle for a Work Area by Means of Metabolic Measurements plus Instrumentation; *Harry J. Halberstadt; M.S. Thesis, June, 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Using a standard medical metabolism tester, a task concerning the optimum angle of inclination for a work surface was administered and reported. The results were compared with data obtained from two previous studies which used the same work surface equipment but employed time to perform the task and energy in horsepower as indicators of the required effort. The results of the metabolic experiment compared closely with results of the other experiments.

2,4. Dial Design; *B. Shackel* **Design,** *1958 (28 Haymarket, London, S.W.1.)*

This article aims to give to industrial designers specific, detailed advice from the literature of human engineering upon the functional design of dials. The various principles enunciated are illustrated with drawings and plates of meter scales and vehicle speedometers.

2,4. The Effect of Diameter on the Effort Required to Rotate Handwheels Used as Cranks; *Herbert T. Fickman; M.S. Thesis, June, 1952; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Five handwheels of different diameter were used by eight operators to overcome varied frictional torque. Analysis of the data indicated that the rate of human energy expenditure decreases with increased diameter of the handwheels.

2,4. Effect of Handwheel Sizes on the Turning Speed; *Paulo V. D. B. Viana; M.S. Thesis, June, 1952; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Investigation was made of the effect of the diameter of handwheels on the maximum speed of turning for various torques applied. Results should provide an approximate solution for the problem of selection of handwheels that allow maximum speed for a given torque.

2,4. Effect of Size of Handwheels on Effort Required for Rotation; *Joad B. Machado; M.S. Thesis, May, 1952; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Tests were run with seven operators, using handwheels of various sizes, to overcome different frictional torques. It was concluded that the larger diameter handwheels are more effective, as far as energy expenditure is concerned, in the range of torques investigated, using the specified method.

2,4. The Effect of Switch-Handle Shape upon the Time Required for Operation; *Richard Henry Doolittle; M.S. Thesis, June, 1952; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The time was measured for 15 operators to rotate a set of 4 switches to 4 different angles using 5 switch handle shapes. It was concluded that the round handle shapes caused the greatest amount of time, and the generally rectangular shapes caused the least.

2,4. The Effect of the Diameter of Handwheels used as Wheel upon the Time Required for Adjustment; *James O. House, Jr.; M.S. Thesis, May, 1952; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Five handwheels, ranging in diameter from four to fourteen inches, with varying axial loads, were used in this experiment. Within the limits of this investigation, the four-inch handwheel appeared to result in the slowest operator performance, while the ten-inch handwheel appeared to result in the speediest operator performance.

2. An Evaluation of Two Methods of Measuring Work Motion Paths; *Harold Eugene Smalley; M.S. Thesis, August, 1947; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

An attempt is made to measure the work motion paths of therbligs which possess fundamentally difficult characteristics and to evaluate the relative accuracy, ease, and limits of the two methods used in the measurement.

2,4. Human Engineering and Electronics; *B. Shackel; M.S. Thesis, June, 1957; Research Psychologist, EMI Electronics Ltd., Hayes, Middlesex, England; (Published by British Communications and Electronics, Russell Street, London, W.C.2.)*

This article reviews the field of human engineering and attempts to show its importance to the electronic engineer. Recommendations upon the optimum design of controls, displays and panel layout are summarized from the literature. Some examples are given from recent electronic components and systems.

2,4. An Investigation of Modifications of Job Design in an Industrial Situation and Their Effects on Some Measures of Economic Productivity; *Arthur Richard Marks; Ph.D. Thesis Nov., 1954; Library, University of California, Berkeley 4, California. (Also see* **Journal of Industrial Engineering,** *November-December, 1956.)*

A study of specialization and effects of productivity followed by enlargement of responsibilities and efforts on productivity, quality and attitudes.

2,4. A Metabolic Investigation of One-Handed versus Two-Handed Work; *Philip J. Thorson; M.S. Thesis, August, 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The results of this investigation, in which eight subjects were tested, disclosed that there is a significant difference of 21% (±3%) in the rate of energy expenditure on a two-handed task over that on a one-handed task.

2,4. A Priori Procedure for Biomechanical Determination of Optimum Motion Pattern; *Gerald Nadler; Ph.D. Thesis, June, 1949; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The results of the application of the *a priori* experimental procedure to the conditions of a simple task involving arm movements indicated that 30° was the optimum angle of inclination between the work surface and the horizontal plane. In an actual time experiment, results indicated that the optimum condition (angle of inclination) was 30°.

2,3. A Proposed Method for the Functional Analysis of Man-Machine Activity to Aid in the Devolpment of Automatic Devices; *Ellsworth M. Ostrom, Jr.; M.S. Thesis; June, 1952; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The objective of this thesis was to develop a method for the analysis of human activity to determine the functions performed, considering the development of automatic devices. The results are, first, the proposed method of analysis and second, an example of its application.

2,8. Rational Procedure for the Design of Household Equipment; *Gerry O'Neil; M.S. Thesis, February, 1949; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

A rational procedure for the design of household equipment was developed by using the tools of motion and time study. Each proposed step of the procedure was listed, discussed in detail, and justified. This rational procedure was applied to the electric range to verify the suitability of the steps.

2,4. A Study of the Effects of the Axis of Inclination upon the Operation of Handwheels; *Russell A. Kasmar; M.S. Thesis, August, 1948; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This investigation measured the speed with which seventeen operators could crank two handwheels at various angles of inclination as directed by a visual stimulus and under specified conditions. The main result noted that the optimum plane angle was in the vicinity of 75 degrees from the horizontal and was not highly critical.

2,4. A Study of the Optimum Angle of Inclination for the Work Surface of a Drafting Table; *Luther W. Thomas; M.S. Thesis, February, 1949; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Investigation was made of the effect of angle of inclination on productivity for three drawing devices: T-square, parallel rule, drafting machine. Results show that there does exist an optimum range of angles for each device tested.

2,4. A Study to Determine the Optimum Position for Instrument or Test Panels by Means of Metabolic Measurements; *Stanley H. Brittingham; M.S. Thesis, June, 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The purpose of this study was to determine whether or not the position of an instrument or test panel relative to the operator is related to the operator's expenditure of energy while performing a task. The results showed that a variation in panel position was not a significant source of variation.

2,4. Time and Energy Relationship of One and Two Hand Activity; *Ralph M. McCugh; M.S. Thesis, June, 1952; Engineering Library, Washington University, St. Louis 5, Missouri.*

Performing simultaneously and symmetrically, Kymograph and Metabulator values from tests with each hand and both show that: 1. no significant difference was found either in oxygen consumption or cycle times between right hand and left hand; 2. significant difference of 53.5% in oxygen consumption and no difference in time between the both hands and the right hand tasks.

3. PLANT ENGINEERING AND DESIGN. *(Plant Layout Analysis Techniques, Plant Layout Basic Principles, Plant Layout Evaluation Procedures, Plant Layout Testing Procedures, Plant Layout Presentation Procedures, Materials Handling Analysis Techniques, Materials Handling Basic Principles, Materials Handling Evaluation and Selection Procedures, Materials Handling Testing Procedures, Materials Handling Equipment Design, Maintenance, Plant Location, Plant Design and Construction, Tool Engineering, Safety, Mechanization, Inspection, Packaging.)*

3,8. An Analysis of Some Methods of Loading-Out Delivery Trucks of Produce Wholesalers; *Joseph F. Herrick, Jr., Stanley W. Burt, Marvin R. Kercho and Anthony Zagarella; Marketing Research Report 15, May, 1952; U. S. Department of Agriculture, Transportation & Facilities Branch, MRD, AMS, Washington 25, D.C.*

This report evaluates six different methods used by produce wholesalers for loading-out produce delivery trucks. Comparison of these methods involves the labor, equipment, and costs.

3,8. Some Aspects of Fluid Flow of Molten Metal in Sand Molds; *Elvin L. Fritz; M.S. Thesis, January, 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Fluid flow of metal in sand molds or simulated sand molds is discussed in this thesis. The type of flow that can be expected to occur in molds is discussed, and the equipment used in the tests is described in detail. Tables and graphs showing the results of flow of mercury in glass tubes and solder in sand molds are also presented.

3. A Classification of Materials Handling Information to Facilitate Equipment Selection; *H. R. M. Souza; M.S. Thesis, May, 1952; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The purpose of this thesis is to classify materials handling information available from books, pamphlets, or magazines, to collect that information, and to present it in a compact form to facilitate selection of equipment for a material handling problem. A final table was prepared to summarize the findings.

3,9. A Computing Procedure for a Line Balancing Problem; *J. R. Jackson; Research Report 44, August, 1956; Management Sciences Research Project, University of California, Los Angeles 24, California.*

A systematic enumeration procedure for the solution of a problem in production line balancing is presented, and illustrated by solving an example. A brief indication is given of the procedure's mathematical justification. Questions of the general efficiency of the procedure are not answered, but work with experimental problems indicates that hand computation will be feasible for many practical problems.

3. Determination of Power Requirements of a Slider-Bed Belt Conveyor with Various Loads, Belts, and Beds; *Jay Goldman; M.S. Thesis, June, 1951; Librarian, Michigan State University, East Lansing, Michigan.*

This thesis concerns itself with the determination of the power requirements of a slider-bed belt conveyor by varying the loads, surfaces and the belts with the other factors held constant. The different belts are rough-top rubber, smooth-top rubber, neoprene rubber, innerbound canvas, impregnated canvas, chemigum, and silver duck canvas top, rubber base. The different surfaces are enameled steel, unpainted hot rolled steel, stainless steel, fir plywood, maple plywood, and aluminum.

3,8. Development of Instrumentation for Machinability Testing; *Philip Henry Beatty; M.S. Thesis, August, 1948; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The author develops instrumentation for use in the field of metal cutting research, and makes recommendations for its use so as to meet a wide variety of situations.

3,8. The Effect of Cutting Compounds on Surface Finish; *Forrest W. Eaton; M.S. Thesis, January, 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

A comparison was made of the effects of old and new cutting compounds. It was found that there was no significant difference between the quality of surface finish obtained by using old cutting compound and that obtained with the new.

3. Equipment Policy for the Large Job Shop; *James F. Fowler; M.S. Thesis, June, 1958; Memorial Library, University of Wisconsin, Madison 6, Wisconsin.*

A study of equipment decisions in plants that produce a diverse line of high value products in low quantity. The thesis covers how data can be obtained, and how economic studies can be made more useful for top level decisions. The sub-titles are "Basic Principles of Modern Equipment Analysis," "Importance of Organization For Effective Equipment Policy," and "Development of Long Range Equipment Planning."

3. An Evaluation of Current Quantitative Techniques in Plant Layout; *J. R. Huffman; Research Report 2, Management Sciences Research Project, University of California, Los Angeles 24, California.*

An analysis of the quantitative techniques currently used for plant layout, with recommendations for a method of planning the flow of products in the plant.

3. A Further Evaluation and Extension of Criteria of Physical-Plant Utilization; *Robert B. Pettitt; M.S. Thesis, June, 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Ten indices have previously been proposed as measurements for the evaluation of physical plant utilization. This paper is a further extension and validation of these proposals. The indices evaluated and retained in this paper are now considered to be valid criteria of physical-plant utilization.

3. Handling and Storage of Apples in Pallet Boxes; *Joseph F. Herrick, Stanley W. McBirney and Earl W. Carlsen; Published as U. S. Government Report, April, 1958; U. S. Department of Agriculture, Transportation & Facilities Branch, MRD, AMS, Washington 25, D.C.*

An interim report covering records on the use of pallet boxes for handling and storing apples. Experimental pallet boxes were built and studied along with those commercially available. Tests showed the apples cooled as well or better than in smaller boxes, fewer apples were bruised, less storage space was required, and costs of using pallet boxes resulted in a saving of $75 to $85 per 1,000 standard box equivalents.

3. Handling Bales of Cotton in Public Warehouses—Methods and Equipment; and Statistical Supplement to Handling Bales of Cotton in Public Warehouses; *Charles D. Bolt and Jo Brice Wilmeth; Marketing Research Report 250, October, 1958; U. S. Department of Agriculture, Transportation & Facilities Branch, MRD, AMS, Washington 25, D.C.*

Principal findings are reported in terms of the relative efficiency and costs of different ways of doing the major handling operations of unloading, weighing, sampling, storing, transporting, breaking out, compressing and loading. The combined man-hour and equipment-hour costs provide a basis for comparing the relative efficiencies of specified handling methods described in the report. The statistical supplement provides detailed basic time and cost data. Tables in the supplement show detailed production data, labor and equipment costs, and also the description of productive data on labor requirements.

3,8. An Investigation of the Effect of Cutting Fluids and Direction of Cutting Fluid Flow upon Form Tool Wear when Cutting Aluminum Bar Stock; *Richard James Cowan; M.S. Thesis, June, 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Efforts were made to determine if tool wear is significantly different for three brands of cutting fluids when the flow is downward on the work and the cutting edge face of the circular form tool, and when the flow is upward on the work and clearance face of a circular form tool. There was no discernible difference in the three fluids. There was no significant difference in the effect of flow direction.

3,8. A Method for Determining Efficient Sizes for Series Type Production Lines with Automatic In-Line Storage; *Gordon R.*

Antelman; M.S. Thesis, March, 1958; Department of Economics, School of Business Administration, University of Minnesota, Minneapolis 14, Minnesota.

This paper concentrates on the problem of determining the number of machines to be employed in each stage of a series type production line and determining amounts of storage capacity to employ between stages under the assumption of multiple shift operation. Machine downtimes are not considered.

3. Methods, Equipment, and Facilities for Receiving, Ripening, and Packing Bananas; *B. G. Andrews and Stanley W. Burt; Marketing Research Report 92, June, 1955; U. S. Department of Agriculture, Transportation & Facilities Branch, MRD, AMS, Washington 25, D.C.*

An evaluation and appraisal of seven methods of receiving, ripening, and packing bananas. The report gives the labor and equipment requirements and costs for the methods studied. The influence of volume of bananas handled on labor and equipment and their costs are fully discussed.

3,8. The Optimum Number of Teeth for Light Duty Milling Cutters; *John Floyd Lipscomb; M.S. Thesis, June, 1952; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

A test to determine the optimum number of teeth for light duty milling cutters, taking into consideration, power, chatter and surface finish.

3,6. The Optimum Procedure for Industrial Progressive Maintenance Based on a Study of Heavy Equipment Manufacturing Plants; *Clifford H. Johnson; M.S. Thesis, August, 1947; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The best methods of maintenance procedures from four plants studied were combined to form the optimum procedure. This procedure indicates the organizational set-up, the duties and functions of each department, and the methods and procedures to be used in operating the maintenance department.

3,8. An Optimum Procedure for the Determination of the Dimensional Limit Capabilities of a Machine Tool; *Edwin W. Engerer, Jr.; M.S. Thesis, June, 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The purpose of this thesis is to test a procedure for determining what specifications can be met by a particular machine. It is concluded that for all practical purposes the results of a test on any diameter in a given range can be applied to all the diameters in that range.

3,4. A Procedure for Decreasing Industrial Accident Susceptibility; *Jack Eugene Woolley; M.S. Thesis, February, 1948; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The accident problem is approached from the individual viewpoint rather than from the angle of mass safety propaganda. A plan of action is set forth for detecting persons with an affinity for having accidents, and then alleviating the faulty human behavior which causes accidents.

3,8. A Procedure for the Determination of Optimum Speeds in Production Equipment; *Herman B. Amster; M.S. Thesis, June, 1948; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Determination of a procedure to obtain optimum speeds of production equipment in general and coil winding machines in particular. Factors: material, forces, power, pressures, setup. Results: use trial and error or standard data if warranted.

3,7,8. A Procedure for the Determination of Synthetic Data for Industrial Quality Control; *Stephan W. Smith, Jr.; M.S. Thesis, June, 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

An investigation of the effect of a change in cutting speed on the dimensional limit capabilities of a machine, so as to determine with a high degree of confidence the upper and lower control limits of a revised control chart as the cutting speed is changed.

3. A Proposal of Criteria for the Evaluation of Industrial Physical-Plant Utilization; *Saze Perry Gantz; M.S. Thesis, June, 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

An extensive survey of the literature on plant layout is presented in this thesis. No quantitative measures of evaluating plant layouts were encountered. From the considerations of good plant layout practice as found in the literature, eleven measurable indices were developed and proposed as criteria of effective physical-plant utilization. A critique of the eleven indices was made in which their applicability to continuous, intermittent, and jobbing layouts were discussed.

3,8. Relationship Between Driving Device and Tool Wear; *Paul B. Eaton; M.S. Thesis, June, 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

An investigation was made of the effect of the driving of the work piece between centers, particularly by the common lathe dog. Results indicated that the lathe dog helps to sustain vibrations, which accelerate tool deterioration.

3,8. Research in Human Engineering Aids Design; *Joseph L. Seminara, and George A. Peters; May 1958; Industrial Laboratories, Relyea Publishing Company, 201 North Wells Street, Chicago 6, Illinois.*

Describes the working relationships which exist between design engineers and human factors consultants or research specialists. Discusses the engineering design stages at which human factors consultation can, most effectively, be accomplished. Gives design examples and sources of information.

3,7. Standard Procedure for Choosing a Sampling Inspection Plan; *William F. McGrath; M.S. Thesis, January, 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

A three section study was made to determine the standard procedure indicated in the title. In conclusion it is believed that the development of a diagrammatic representation for the selection of a sampling plan is a novel procedure which should be beneficial to those installing a sampling plan.

3,7. A Statistical Analysis of Inspection Gages; *James L. McKenney; M.S. Thesis, June 1952; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The purpose of this paper was to investigate the accuracy and repeatability of operators using various precision measuring instruments. It was determined that the operators tended to arrive at dimensions less than the "true" dimension of a part on outside dimensions.

3. A Statistical Approach to an Optimum Storage Layout for Materials Handling Economy; *George William Bechberger; M.S. Thesis, February, 1948; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The author shows that optimum storage area can be determined by statistical means, and that such an approach can effectively and systematically be used under the existing conditions for the layout under consideration.

3,8. A Statistical Approach to Metal Cutting Experimentation; *T. M. Jacob; M.S. Thesis, January, 1952; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

A 5×5 graeco-latin square is designed to conduct an experiment for determining the concurrent effect of surface speed, depth of cut, side-cutting-edge angle, and material on surface finish and tool wear. The results show that depth of cut is the highly significant factor affecting tool wear, while side-cutting-edge angle affects surface finish the most.

3. A Study of Present Steel Plant Locations in the United States to Determine Whether they are Vulnerable to Air Attack due to Lack of Dispersion; *Gerald H. Ray; M.S. Thesis, 1949; Library, University of Pittsburgh, Pittsburgh 13, Pennsylvania.*

Plant dispersion is a subject of considerable emphasis during war time, especially to a country undergoing bombardment of its industrial sections. Reliance upon accidental dispersion of these plants is not satisfactory; consequently, intensive peace time planning should be given to dispersion. Basic steel making plants have been chosen for analysis in this study.

3. A Study to Determine the High Industrial Accident Periods: Time of Day, Day of Week, and Month of Year; *Lawrence Mann, Jr.; M.S. Thesis, February 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

A study of accident data from eight plants led to the following conclusions: 1. It appears that the hour of day is an external factor to which the accident rate is related; 2. indications are that variations in the frequency of accidents from month to month are not attributable to chance alone; and 3. the probability that the day of the week is related to accident frequency is small.

3,4. Visual Inspection of Products for Surface Characteristics in Grading Operations; *Donald G. Malcolm and E. Paul DeGarmo; Marketing Research Report 45, June 1953; U. S. Department of Agriculture, Transportation & Facilities Branch, MRD, AMS, Washington 25, D.C.*

This report describes the results of basic research done on grading operations. It specified within narrow limits the speeds of translation and rotation which objects should pass an inspector for the optimum efficiency. This work reports results with various shaped objects, the influence of color, the approach of the object to the sorter, and the quality of the incoming lots to be sorted on inspection efficiency.

4. HUMAN ENGINEERING. *(Motivation and Psychological Aspects, Physiological Aspects, Sociological Aspects, Biomechanics, Arbitration, Collective Bargaining, Labor, Training, Learning, Job Evaluation, Wage Incentive Plans, Selection of Personnel.)*

4. An Analysis of Profit and Wage Trends; *Ralph L. Miller, M.S. Thesis, June 1948; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This work advances an analysis of the financial reports for 168 organizations in the steel industry or industries manufacturing products made from steel. An attempt is made at determining what the average wage and profit trends have been, and to what extent the average wage could be increased by the average profit realized or by the average profit increase over the preceding year.

4. An Analysis of the Factors Affecting Time Study Grievances; *Roland Henry Watson, M.S. Thesis, June 1952; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Records from fourth-level grievances arising within General Motors Corporation and Ford Motor Company were studied. Comparisons were made between types of grievances in these companies, the frequency of occurrence of different types and severity of the umpire's decision for each company's cases.

4. An Analysis of the Factors Contributing to an Acceptable Beneficial Suggestion; *Frederick C. Humphreys; M.S. Thesis, June 1954; Inter-Library Loan Service; Purdue University, Lafayette, Indiana.*

Past files of beneficial suggestions from three naval shore establishments were separated into two groups, acceptable and not-acceptable, and were analyzed in the light of twenty-four carefully selected factors. It was concluded that it is possible to measure and place in rank order those factors that contribute to a winning beneficial suggestion.

4. A Comparison of Collective Bargaining Agreement Provisions for Three Industrial Labor Market Areas in Indiana; *James D. Farmer; M.S. Thesis, June 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Differences between provisions in the three areas were compared and analyzed statistically. The labor market area influences provisions from that area, while less than ten percent of the provisions show significant differences at a ninety-five percent confidence level.

4,8. A Concept of Predetermined Labor Requirements as a Function of Production Control; *John P. McEvoy; M.S. Thesis, June 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Application is made of the control techniques for machines and materials to the third element of production, labor. The results of the study indicate that the use of predetermined labor requirements to attain improved control over the labor element of production seems entirely feasible.

4. Determination of the Effect of Performing a Simple Task over a Prolonged Period on the Rate of Energy Expenditure; *John Henry Behl, M.S. Thesis, June 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The object of this thesis was to take three simple tasks and find the effect on energy expenditure of performing these tasks for sixty-four minutes without interruption. The results indicate that the energy expenditure rises rapidly at the beginning of the task and does not change significantly for at least a period of sixty-four minutes.

4. The Effect of Music on the Metabolic Rate of Workers; *Wayne D. Surface; M.S. Thesis, June 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The body metabolism rates of ten persons were measured while these persons were subjected to backgrounds of noise and to backgrounds of noise plus music. A statistical analysis of the metabolic rates thus obtained indicates that there is no significant variation between the rates for the three musical selections nor is there a significant variation between the rates for the conditions of noise versus noise plus music.

4. The Effect of Praise and Reprimand on Workers' Energy Expenditure; *James A. Marks; M.S. Thesis, June 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

A Sanborn metabolic tester was used to measure the energy expenditure of six male and six female operators performing a simple task. In most cases praise and reprimand had little or no effect on worker energy expenditure and little or no difference was noted between the effects on male and female operators.

4. Errors of Estimate in Operational Analysis; *George A. Peters; Research Project, December 1957; (Also see Operations Research, 1957, Volume 5, Number 6.)*

A case study report of possible errors of estimate in the human components of a machine system in operational analysis. Implica-

tions in regards to management decisions and methodology are discussed.

4,9. The Gap Between the Electronic Engineer and the Accountant; *P. Kircher; Research Report 39, December 1953; Management Sciences Research Project, University of California, Los Angeles 24, California.*

A careful study of a company's data processing needs and the capabilities of computing machines. Some of the major requirements of typical accounting systems are explained in order to show the engineer some of the problems he must meet.

4,6. Human Engineering—A New Occupation; *George A. Peters and Lewis R. Drumm;* **The Personnel and Guidance Journal,** *December 1957, Volume 36, Number 4.*

This article provides basic information on the job duties, requirements, related job titles, recommended academic preparation for employment, salary levels, the current status, and the possible future needs for human engineers.

4. Human Engineering: An Outmoded Term; *George A. Peters; Joseph L. Seminara; Article Published in December 1957;* **The American Psychologist,** *Volume 12, Number 12, Pages 751-752; The Journal of The American Psychological Association, Washington, D. C.*

To avoid the use of the term human engineering or engineering psychology by those not professionally trained as engineers, a proposed occupational nomenclature for the field of human factors, engineering is described.

4,6. An Investigation of Industrial Engineering Functions and Personnel; *Benjamin Hancel Bonds and Paul Edward Overcast; M.S. Thesis, June 1956; Industrial Engineering Department, University of Houston, Cullen Boulevard, Houston 4, Texas.*

This thesis and report is based on an extensive survey of 153 representative industrial firms, 103 which had Industrial Engineering Departments (out of nearly 1,000 solicited). The questionnaire used was divided into two main sections: 1. Industrial Engineering functions and 2. Industrial Engineering personnel. Conclusions reached indicate the increasing importance and recognition of both the Industrial Engineering function as well as the Industrial Engineer himself.

4,6. Occupational Possibilities for Technical Institute Graduates; *Donald G. Metz; M.S. Thesis, June 1949; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The Dictionary of Occupational Titles, United States Employment Service, was established as a frame work on which to base this procedure by a personal survey of the actual placement of technical institute graduates. A list of occupations, including industries where found, brief definitions, and alternate titles, was established for the electrical technology curriculum.

4,8. Optimum Speeds of Indexing Devices; *Donald G. Malcolm; M.S. Thesis, June 1948; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This research was undertaken to find any inter-relationships that might exist between various operator's production versus machine speed curves. Results indicate that 83% of the operators considered achieved their maximum production within a range of ±5% of 87% production.

4,12. A Plan for Evaluating Instructional Jobs at the University Level; *Robert L. Sauer; M.S. Thesis, August 1948; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The use of formal plans of job evaluation for the purposes of salary determination of instructional jobs of colleges and universities is in the embryonic stage. This paper presents a short plan for accomplishing this objective. The plan shows a reliability which is significantly higher than that obtained by a simple ranking of the same jobs.

4. A Position Evaluation Plan for Clerical and Technical Positions; *Fred E. Kindig; M.S. Thesis, 1947; Library, University of Pittsburgh, Pittsburgh 13, Pennsylvania.*

Job evaluation of salaried positions was largely an unexplored field, especially as applied to a wide range of positions, when this thesis was written. A system is described for clerical and technical positions and the implementation of this system in a large manufacturing organization is considered.

4. Predetermination of Weights to be Assigned to Job Evaluation Factors and Degrees; *Dean W. Freed; M.S. Thesis, June 1948; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This analysis represents an effort to design a more objective method of establishing the point values to be assigned to the various degrees of each factor of a point rating job evaluation plan.

4. A Procedure for Appraising Personnel Practices in Small Companies; *Frank X. Starshak; M.S. Thesis, June 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This thesis develops a check list of personnel practices and industrial relations, adapted from a check list for use in a naval industrial activity. Twelve companies were selected for the application of this procedure, to determine whether they were using generally acceptable practices, and to show any differences between the practices of the different companies.

4. A Procedure for the Appraisal of Personnel Practices in a Naval Industrial Activity; *Julian E. Rawls; M.S. Thesis, June 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

A check-list procedure was tested at the U. S. Naval Ammunition Depot, Crane, Indiana, and the U. S. Naval Ordnance Plant, Indianapolis, Indiana, to check the effectiveness and coverage of the procedure. The applications of the check list gave a measure of proof that the procedure was sound.

4. Relationship Between Disciplinary Record of U. S. Naval Enlisted Personnel and General Classification Test, Age of Enlistment, and Other Factors; *Kevin E. Byrne; M.S. Thesis, June 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Evaluation of relationships indicated that the best criterion to use in the selection of naval personnel in order to reduce disciplinary cases appears to be the criterion of years of school. There is also a significant correlation between the disciplinary record and the following factors: 1. years of school; and 2. years of service.

4. Relationships Among Various Factors Affecting Industrial Relations in the Chemical Industry; *Robert C. Forney; M.S. Thesis, June 1948; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This study attempts to determine the relationships which exist in the chemical industry among plant size, unionization and shift operation, and further to ascertain the relationship of these factors to industry-wide bargaining, hours of work, job analysis, special factors in the wage structure, employee benefits, labor-management disputes, technological unemployment, and labor-management cooperation.

4,7. A Statistical Approach to a Wage Incentive Plan Designed to Maintain Quality; *John C. Scheibenberger, Jr.; M.S. Thesis, June 1949; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

There is a tendency toward decreased quality as a result of increased production when incentive plans are instituted in manufacturing. Here Statistical Analysis is used to develop a plan to measure the quality of parts produced and to adjust the incentive so that quality is maintained.

4. A Study of the Effect of Wage Incentive and Non-wage Incentive Jobs on the Accident Rate; *Raymond J. Pajkowski; M.S. Thesis, August 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Accident data from sixteen companies were gathered and analyzed statistically. Within the limitations stated in the thesis, it appears that there is no significant difference in the accident frequency and severity rates for incentive and non-incentive jobs.

4. A Survey of the Duties and Responsibilities of Time Study Engineers in the Indianapolis Area; *Robert A. Jacobs; M.S. Thesis, June 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

A survey was made of twenty-five firms which have employees functioning as time study engineers to gather data concerning the duties and responsibilities of such engineers. The results were compiled into a composite job description for the job of time study engineer.

4. Training and Training Research; *Robert Glaser and Murray Glanzer; Research Project, August 1958; American Institute for Research, 410 Amberson Avenue, Pittsburgh 32, Pennsylvania; Contract Nonr-2551(00).*

Research on team training for guided missile operations.

4. The Validation of Predictions Concerning Personnel and Training Requirements; *Murray Glanzer and Robert Glaser; Research Project, August 1958; American Institute for Research, 410 Amberson Avenue, Pittsburgh 32, Pennsylvania; Contract Nonr-2551(00).*

Research on team training for guided missile operations.

5. ENGINEERING ECONOMICS. *(Replacement Theory, Amortization Theory, Interest Rate Concepts.) (Note: There were no abstracts received for this classification.)*

6. ORGANIZATIONAL PLANNING. *(Decentralization Concepts, Social Scientist's Aspects, Control Design, Communications, Information Theory, Organization Design, Financial Planning.)*

6. The Academic Literature-Science Unit; *William F. Hewitt, Jr.;* **Journal Chemical Education,** *26: 191-192, 1949.*

The inadequacy of present communications in science is felt keenly by the academic scientist. A "self-help cooperative" is described, by means of which academic scientists can cover the literature and build an abstract file. Questionnaire returns indicate existence of a demand for services that such a group might perform.

6. Oral Communication in Executive Behavior in a Medium Sized Industrial Firm in Detroit, Michigan; *Chester L. Brisley; Ph.D. Thesis, 1957; Wayne State University, Detroit, Michigan.*

This study is significant and distinctive because the company analyzed has a participating committee type management called "multiple management." Therefore, discussion is used to the fullest extent. The study introduces a methodology called "work sampling" for measuring quantitatively the amount of communication taking place. Further, the study evaluated from a qualitative point of view through depth interviews the effectiveness of, as well as the approaches to, communication.

6. Factors Affecting the Employment of Engineers in Indiana; *Robert E. Walker; M.S. Thesis, August 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Returns from a questionnaire to manufacturing companies in Indiana were analyzed. The data give some idea of the duties performed by engineers, the proportion of engineers to total employees, and the effects of the use of engineers.

6. Some Needs of Louisiana State Industry in the Field of Engineering Management; *Kenneth Maxwell Loughmiller; M.S. Thesis, June 1948; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

General Survey of engineering management needs in Louisiana.

6. The Organization and Administration of an Employee's Magazine; *Philip R. Sheridan; M.S. Thesis, August 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This paper explains the need for employee publications and presents the essential elements of the purpose, management, and evaluation of an employee magazine. Methods used by the author while editing an employee magazine resulted in slightly higher than normal interest in, and readership of, the magazine as compared with other employee magazines.

6,10. Recent Developments in Input-Output-Analysis; *T. Fabian; Research Project 51, September 1956; Management Sciences Research Project, University of California, Los Angeles 24, California.*

Dynamic input-output, inter-regional analysis and process analysis, and the application of linear programming to inter-industry studies are reviewed and compared with the theory of general economic equilibrium.

6. Science Communications; *William F. Hewitt, Jr.;* **Science** *114: 134-135, 1951.*

A new section of the American Association for the Advancement of Science is suggested, or formation of an interdisciplinary Committee of Science Communications. Documented information is presented as to the magnitude of the communications problem in science, and some of the means considered for its solution.

6. Working Capital Model; *P. Kircher and R. Rothschild; Research Project 38, Management Sciences Research Project, University of California, Los Angeles 24, California.*

Demonstration of the development and use of a working capital model, based upon scientific study of the relationship between the volume of sales and the size of individual working capital items. This paper proposes a method of planning expenditures under fluctuating sales conditions.

7. INDUSTRIAL STATISTICS. *(Sampling Concepts, Acceptance Sampling, Quality Control Techniques.)*

7. A Bivariate Generalization of Student's t-distribution, with Tables for Certain Special Cases; *C. W. Dunnett and Milton Sobel; Research Project, June 1954; Sibley School of Mechanical Engineering, Cornell University, Ithaca, New York; (Published in* **Biometrika,** *Vol. 41, pp. 153-169).*

A multivariate generalization of student's t-distribution is considered. The bivariate case is treated in detail; exact and asymptotic expressions for the probability integral and an asymptotic for certain percentage points are obtained. Tables are given for the case where the correlation coefficients $= \pm 0.5$.

7. An Investigation of the R/d2 Estimate of Standard Deviation; *Joseph Movshin; M.S. Thesis, January 1952; Engineering Library, Washington University, St. Louis 5, Missouri.*

A means of estimating the reliability of a standard deviation found from the control chart average range is presented. A ratio called $J = (\overline{X}\text{-median})/\sigma\overline{R}$ is developed for the reliability estimation.

7. Multiple-Decision Procedures for Ranking Means; *Robert E. Bechhofer; Proceedings of Ninth Annual Convention ASQC, pp. 513-519.*

The problem of selecting that one of k normal populations which has the largest population mean is considered. The objective is to guarantee that the probability of a correct selection is equal to or greater than a specified constant $P^* < 1$ whenever the difference between the largest and second largest population mean is equal to or greater than a specified constant $\delta^* > 0$. A single-sample procedure is presented for accomplishing this objective when the population variances are equal and known. A table for applying this procedure is given. The application of the procedure is motivated by a practical example.

7. A Property of the Multinomial Distribution; *Harry Kesten and Norman Morse; February 1958; Sibley School of Mechanical Engineering; Cornell University, Ithaca, New York. (Accepted for publication by* **Annals of Mathematical Statistics.***)*

In this paper the following result is proved: let $p_1 \leqq p_2 \leqq \ldots \leqq p_k$ be the population probabilities of a k-nomial distribution, and suppose the procedure of Bechhofer, Elmaghraby, and Morse (see above) is used. Then for all configurations of the p_i's such that $\Sigma p_i = 1$ and $p_s/p_s - 1 \leqq \theta^*$, the probability of correct selection is minimized when $p_i = \ldots = p_{k1} = 1/(\theta^* \; k\text{-}i) = p_s/\theta^*$.

7. A Sequential Multiple-Decision Procedure for Selecting the Best One of Several Normal Populations Various Experimental Designs; *R. E. Bechhofer;* **Biometrics,** *Vol. 14, pp. 408-429.*

Sequential procedures for selection of the best one of several normal populations are given. The procedures terminate with probability one and guarantee that the probability of a correct selection is at least equal to some specified probability whenever the largest population mean differs from the second largest by some specified amount. The method of applying the procedure with various experimental designs is described. Approximate methods involving substantially less computation are also given, as is a numerical example.

7. A Single-Sample Multiple-Decision Procedure for Ranking Variances of Normal Populations; *Robert E. Bechhofer and Milton Sobel;* **Annals of Mathematical Statistics,** *Vol. 25, pp. 273-289.*

A procedure for solving the problem posed in the title is described. Exact small-sample methods and a large sample method are given for computing the sample sizes necessary to guarantee a preassigned probability of a correct ranking, under specified conditions on certain variance ratios. Some tables computed by these methods are provided.

7. A Single-Sample Multiple-Decision Procedure for Selecting the Multinomial Event which Has the Largest Probability; *R. E. Bechhofer, S. Elmaghraby and N. Morse; September 1957; Sibley School of Mechanical Engineering, Cornell University, Ithaca, New York. (Accepted for publication by* **Annals of Mathematical Statistics.***)*

The problem suggested in the title is formulated as a multiple-decision selection problem. A single-sample procedure is proposed which guarantees: "The probability of a correct selection is $\geqq p^*$ whenever the true ratio of the largest to the second largest of the population probabilities is $\geqq \theta^*$, where p^* and θ^* are specified in advance. Large and small sample methods of obtaining the sample size required are given; tables and sample calculations are provided.

7. Statistics of Extreme; *E. J. Gumbel; September 1958; Columbia University Press, Columbia University, New York 27, N.Y.*

This book deals with the exact distribution of extreme values for given initial distributions and the asymptotic distributions of extreme values for classes of initial distribution. In addition it contains numerous applications of these theories to floods and droughts, geological problems, and to the breaking strength of material and fatigue failure.

7. A Two-Sample Multiple Decision Procedure for Ranking Means of Normal Populations with a Common Unknown Variance; *R. E. Bechhofer, C. W. Dunnett, and M. Sobel;* **Biometrika,** *Vol. 41, pp. 170-176; June 1954.*

The problem of ranking the means of k normal populations as well as the less complex problem of selecting the population with the highest (or lowest) mean, is solved for the case where the variances of all k populations are equal, but the common value is unknown. A numerical example is given.

8. PRODUCTION CONTROL. *(Inventory Control, Forecasting, Scheduling, Dispatching, Routing, Process Research, Product Research, Analysis and Measurement Techniques for Planning and Control, Receiving and Shipping, Stockkeeping and Warehousing, Control Models and Simulation.)*

8. Application of Economic Lot-Size Formulas to Procurement; *Clifford George Bigelow; M.S. Thesis, May 1953; Egleston Engineering Library, Columbia University, New York 27, New York.*

The extent to which some industrial organizations use economic lot-size formulas for the determination of purchase order quantities is discussed. The ordering procedures in use at Westinghouse Electric, Bell Telephone Laboratories, Cutler-Hammer, and General Foods are analyzed. The lot-size formula of Professor Ralph C. Davis of Ohio State University is mathematically derived.

8. Detailed Scheduling of Industrial Production Activities; *J. R. Jackson; Research Report 31, November 1952; Management Sciences Research Project, University of California, Los Angeles 24, California.*

A mathematical model is used to represent the "job lot" scheduling problem. It considers the detail production schedule or "micro-programming" problem from an analytical point of view.

8,9. Electronic Data Processing Machine Requirements; *R. G. Canning; Research Report 16, March 1955; Management Sciences Research Project, University of California, Los Angeles 24, California.*

This report describes in more detail the electronic "computer" part of the production control system considered in *Research Report 30,* for the routine processing of clerical data. Major differences between this machine and today's mathematical machines are discussed.

8,9. Electronic Scheduling Machine Requirements; *R. G. Canning; Research Report 29, March 1955; Management Sciences Research Project, University of California, Los Angeles 24, California.*

This report describes machine requirements for the processing of the shop scheduling problem. It indicates how present day machines might be applied to this widespread production problem

and how specialized machines could be developed for more economical solution of the problem. The difference between a machine for routine data processing, and one for management decision-making assistance is described.

8,10. Etude Statistique de la Fatigue des Materiaux; *E. J. Gumbel;* **Revue de Statistique Applique,** *1957, vol. V., No. 4, 11 Rue Pierre Curie, Paris, France.*

This paper first states the logical prerequisites for any analysis of fatigue and breaking strengths by introducing the survivorship functions. After a short explanation of the theory of extreme values one of the asymptotic theories of smallest values is used for the analysis, and the construction of the *S, N curves.* Methods are shown for the estimation of the minimum life and the endurance limit. Twenty series of observed fatigue lives show a good agreement to the theory. Finally, new methods of experimentation are proposed.

8,9. An Experimental Investigation of Scheduling for Single-Step Production; *Richard W. Conway; Ph.D. Thesis, February 1958; Department of Industrial and Engineering Administration, Upson Hall, Cornell University, Ithaca, New York.*

A review of the literature of the scheduling problem, an analysis of various aspects of single stage production, and development of a digital computer simulator for the problem using an IBM 650 computer. The development includes consideration of variable set-up times depending upon product sequence, four products, loss or penalty costs for late delivery, storage costs and interaction on lot sizes. A series of priority rules are studied, under conditions of various cost parameters, deterministically varying demand, and various shop load conditions. Conclusions are drawn with respect to goodness of the procedure, saturation of the facility, lot size determination and digital simulation in general.

8. Exploding Manufacturing Outlines: *J. R. Jackson; Research Project 33, March 1953; Management Sciences Research Project, University of California, Los Angeles 24, California.*

A mathematical formulation of problems describing industrial or productive capacity. A given collection of information would constitute a description of plant capacity if one can determine whether long-term average production rates can be achieved.

8. The Evaluation and Improvement of a Procedure for the Analysis of a Production Control System in a Job Lot Industry Making Sponge Rubber Products; *Richard Dickinson Frick; M.S. Thesis, June 1952; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This thesis evaluates and suggests improvements to the latest development of a procedure for the analysis of a production control problem. It was desired to develop a procedure which is flexible enough to be used in any job lot industry. The study is based upon the operation of a plant manufacturing sponge rubber parts for the automotive industry.

8. The Evaluation and Improvement of a Procedure for the Analysis of the Production Control Problem in a Job Lot Industry; *Jack Scheip Whitmer; M.S. Thesis, June 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

As a continuation of a previous investigation of the analysis of plant production control, the production control system of a lacquer manufacturing company is analyzed and improvements suggested.

8. An Evaluation of the Various Concepts of the Routing Function of Production Control as Indicated by Current Literature; *T. S. Joseph; M.S. Thesis, June 1950; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Through a survey of current literature the operations with which the routine function is concerned were determined. It was found that most writers and production men regard knowledge of the availability of machines as the essence of the routing function.

8. An Investigation into the Design of an Improved Flat Plate Solar Energy Absorber; *C. B. Gambrell, Jr.; M.S. Thesis, August 1952; University of Florida, Library, Gainesville, Florida.*

A new type solar absorber was designed to incorporate manufacturing ease, minimize investment, and effective material utilization. Several absorbers were built of different metals utilizing the flat plate design, and when tested were found to be superior to the conventional coil type absorber in all respects.

8,10. Job Shop Scheduling—An Application of Linear Programming; *R. T. Nelson; Research Report 28, March 1954; Management Sciences Research Project, University of California, Los Angeles 24, California.*

The factors which describe the difference between shop loading and scheduling are discussed. A small scale job shop scheduling problem is presented to illustrate a use of linear programming for industrial scheduling.

8,9. Job Shop Simulation by the Logistics Computer; *J. R. Jackson; Research Report 49, March 1956; Management Sciences Research Project, University of California, Los Angeles 24, California.*

A report on computations carried out by Jackson and W. H. Marlow, to study various rules for deciding what a machine should do "next" in an idealized and simplified machine shop.

8. A New Concept of Metal Removal Work Units and Their Relation to the Capabilities of Machine-Tools; *Ary M. Jones; M.S. Thesis, June 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The purpose of this thesis is to introduce a new concept of metal removal work units with the objective of helping the planner in his work of writing up a standard process sheet. From the adopted procedure it was found that the proposed group of work units includes practically all the work units in present-day use in metal removal.

8. Notes on Some Scheduling Problems; *James R. Jackson; Research Report 35, October, 1954; Management Sciences Research Project, University of California, Los Angeles 24, California.*

A theorem is proved which generalizes the 2- and 3-machine schedule problem solutions of S. M. Johnson, and is applied to several problems. In particular, the 2-machine problem is solved in the following cases: 1. possibly large, but not widely varying, transportation times are required for the job-lots between their processing by the first and the second machine; 2. the second machine may start processing a job-lot before the first machine has completed the entire lot; and 3. the setting up of the second machine for a given job-lot can start before the first machine has actually completed the lot.

8,10. A Partial Ordering Determined by Certain Matrices; *J. R. Jackson; Research Report 32; Management Sciences Research Project, University of California, Los Angeles 24, California.*

The paper characterizes a simple property of matrices from the point of a mathematical description of industrial production scheduling.

8,10. Precedence Matrices; *E. W. Barankin; Research Report 26, December 1953; Management Sciences Research Project, University of California, Los Angeles 24, California.*

The main purpose of the analysis of precedence matrices is to devise a criterion for recognizing when a set of precedence relations P is consistent; that is, one which has no mutually contradictory requirements. The scheduling or temporal ordering of items establishes a set of precedence requirements which may imply other precedence relations.

8. A Procedure for Determining the "Work-Units" of the Metalworking Machines; *Richard Franklin Adams, M.S. Thesis, June 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

A procedure is described that allows one to collect and classify, in systematic order, the various terms used in the metalworking industries. Information was obtained from mailed questionnaires.

8. A Procedure for Evaluating Alternative Farm Processes; *Keith W. Hardy; M.S. Thesis, January; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This thesis develops a procedure for adapting the scientific approach as used by the Industrial Engineer to farm processing. The procedure was applied to hay drying to show how it may be used.

8. A Procedure for the Analysis of the Production Control Problem in a Job-Lot Industry; *James J. Cavin; M.S. Thesis, June 1949; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

A procedure for analysis was formulated using former analyses and other available information. It was found that most analyses included such factors as type and volume of production, layout of plant, company organization, and others. A tentative procedure was adopted which was composed of five of the above factors.

8,10. Process Analysis of the Iron and Steel Industry: A Model; *T. Fabian; Research Report 47, August 1957; Management Sciences Research Project, University of California, Los Angeles 24, California.*

A linear programming framework is presented for predicting the capacity of the iron and steel industry to produce various mixes of final products. It is pointed out how this framework can be used as a starting point for the development of models representing various production planning problems in an integrated steel mill.

8. Process Control for Cold Worked Stainless Steel; *Lester A. Kessler and Robert W. Cunny; M.S. Thesis, January 1948; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The elastic and plastic behavior of cold worked stainless steel was analyzed when subjected to tension, compression and torsion. The control developed was that the true stress-strain curve of the material tested must fit the corresponding standard curve, and also intersect the true strain axis at the same point or within specified limits.

8,9. Production Control Through Electronic Data Processing: A Case Study; *R. G. Canning; Research Report 30, May 1954; Management Sciences Research Project, University of California, Los Angeles 24, California.*

This report, a consolidation of several previous reports, describes the production control problem present in many of the larger manufacturing plants, and the methods now in use under manual data processing systems. All of this information is presented in the language of the shop. Next, the general approach to electronic data processing is described, following which the details of an electronic system designed to meet the requirements of one local plant are outlined. Cost estimates and savings estimates are presented.

8. Production Rates and Inventories; *T. Fabian and R. T. Nelson; Research Report 22, August 1953; Management Sciences Research Project, University of California, Los Angeles 24, California.*

A model is developed for determining the constant rate of production which will maximize profit for a period of known demand, subject to a set of given assumptions.

8,10. Research Problems in Production Routing and Scheduling; *A. J. Rowe and J. R. Jackson; Research Report 46, October 1956; Management Sciences Research Project, University of California, Los Angeles 24, California.*

The interdependence of the problems of choosing routings, lot sizes, and scheduling methods is discussed, and it is suggested that these problems be studied by the use of electronic computers to perform simulated experiments. The application of this technique is described in general, and an illustrative example is given. Specific problems are discussed, and research to date concerning scheduling methods is outlined.

8. Scheduling a Production Line to Minimize Maximum Tardiness; *J. R. Jackson; Research Report 43, July 1955; Management Sciences Research Project, University of California, Los Angeles 24, California.*

Suppose a production-line must process a given bill of goods, made up of job-lots each of which requires a certain amount of the line's time. Further, suppose that tooling, raw material needs, etc., determine for each job-lot an earliest possible starting time, and that the completion of each lot is desired by some given due-time. This paper considers the problem of scheduling the required production in such a way as to minimize the maximum of the tardinesses of the items. Two cases are examined. In the first case, where the time required by any given job-lot can be split into several intervals if desired, the problem is solved completely. The second problem is that in which each job-lot must be assigned a single continuous interval. This problem is reduced to a finite problem which is examined in detail, computing procedure being given whereby one can isolate a relatively small number of schedules which must include at least one solution. It is pointed out that the computing procedure can also be used to solve several related problems.

8. A Simplified Formula for the Determination of Economic Production Lot Sizes; *Yi-Chia Chao; M.S. Thesis, June 1949; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This thesis seeks to provide a simplified formula for determining the economic production lot size and graphical charts for its ready application. Through study of existing formulae and investigation of all factors affecting lot sizes, the proposed simplified formula is developed.

8. A Statistical Procedure for the Determination of Adequate Inventory Levels for Variable Manufacturing Conditions; *Robert E. Koogler; M.S. Thesis, June 1949; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

A specific problem encountered at the overhaul base of a major U. S. airline is presented, and statistical methods of computing minimum inventory requirements are suggested as part of the problem's solution.

8. A Survey of Waste Elimination in Welding Production Activity; *Louis K. Birinyi; M.S. Thesis, June 1951; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This study is a review of articles which record success in

waste elimination in production welding. From these production experiences, a check list of questions for a general methods analysis approach in the fields of electric-arc, oxyacetylene-gas, and resistance welding is developed.

8. SWAC Computations for some $m \times n$ Scheduling Problems; *R. T. Nelson and J. R. Jackson; Research Report 48, March 1956; Management Sciences Research Project, University of California, Los Angeles 24, California.*

A summary of the results of exhaustive computations on a highly specialized class of 2- and 3-machine problems.

8,10. Various Aspects of the Distribution of Fatigue Lives; *E. J. Gumbel; July 1958; Wright Air Development Center, Ohio; WADC Technical Report 58-72, ASTIA Document No. 155747.*

The report presents transformation of the probability functions for large values of the scale parameter, probability function for the relative life defined as the fatigue life divided by the characteristic value, relation between scale-parameter and minimum life, and nomograms for the rapid estimation of the parameters of the probability function.

8. Various Optimizers for Single Stage Production; *W. E. Smith; Research Report 41, August 1955; Management Sciences Research Project, University of California, Los Angeles 24, California.*

This report develops theorems which enable one to schedule operations on a single-stage production system so as to minimize certain functions or optimizers. It is shown that the maximum tardiness of a job completion is minimized by ordering the jobs according to the date job is due to be completed. The sum of times until each job is completed may be minimized under various conditions. If all jobs can be completed by their due-dates, a rule is given whereby a weighted sum of completion times can be minimized subject to all jobs being completed by their due-dates.

9. DATA PROCESSING SYSTEMS DESIGN. *(Digital Computers, Analog Computers, Accounting Equipment, Desk Equipment, Auxiliary Equipment, Analysis Techniques.) (Note: There were no abstracts received for this classification.)*

10. OPERATIONS RESEARCH AND SYSTEMS DESIGN. *(Linear Programming, Waiting Line Theory, Simulation Concepts, Game Theory, Monte Carlo Concepts, Probability Theory.)*

10. The Cost and Value of Reports—A Case Study in a Telephone Company; Marvin A. Griffin; *Research Project, October 1958; Johns Hopkins University, Baltimore, Maryland. (To Be Published in* **Operations Research and Systems Engineering,** *the Johns Hopkins Press.)*

This study attempts to optimize the utility derived from a system of reports. An attempt is made to measure the value derived from a system of reports as well as the costs associated with the manufacture of the system. Utility is the difference between value and cost.

10. On the Existence Problem of Linear Programming; *J. R. Jackson; Research Report 9, February 1953; Management Sciences Research Project, University of California, Los Angeles 24, California.*

A discussion and proof of the existence of a solution in linear programming.

10. Mathematical Methods in Management Programming; *M. E. Salveson; Research Report 34, June 1954; Management Sciences Research Project, University of California, Los Angeles 24, California.*

Consideration of linear programming methods for computing production programs. The computational method is discussed.

10. Multivariate Distributions with Given Margins; *E. J. Gumbel; July 1958; Office of Ordnance Research, Box CM, Duke Station, Durham, North Carolina.*

There is an infinity of bivariate probability functions such that two given probability functions are marginal. A system of multivariate distributions for given marginal distributions is developed. The solutions are not unique. This system includes a bivariate distribution with marginal uniform distributions where the regression curves are linear and a bivariate distribution with normal marginal distributions where the regression curves are not linear. The coefficient of correlation within this system varies only from $-\frac{1}{3}$ to $\frac{1}{3}$ and these two limits are reached for the uniform distribution. The author shows an exponential bivariate distribution where the correlation has only one fixed value.

10. Networks of Waiting Lines; *J. R. Jackson; Research Report 53, February 1957; Management Sciences Research Project, University of California, Los Angeles 24, California.*

Derivation of steady-state probabilities of an otherwise simple system of multiple servers in which customers move from department to department probabilistically.

10. Statistical Theory of Floods and Droughts; *E. J. Gumbel; May 1958;* **Journal of the Institution of Water Engineers,** *Vol. 12, No. 3, May 1958, Parliament Mansions, Abbey Orchard Street, London S.W. 1, England.*

The floods are considered as the largest and the droughts as the smallest mean daily discharges during a given year. Since the distribution of the discharges is unknown, the asymptotic theory of extreme values is used for an analysis of the floods and droughts. To this end, a probability paper is used. Many series of observed floods and droughts show a good agreement to the theory.

10. Stochastic Search for the Maximum of a Function; *E. W. Barankin; Research Report 20, July 1953; Management Sciences Research Project, University of California, Los Angeles 24, California.*

A study of the stochastic convergence of a sequence of random variables conditioned by conditional probabilities. The problem is to find analytic conditions of the sequence of random variables which have large values for the conditional probabilities which will insure weak and strong stochastic convergence.

10. Toward Quadratic Programming; *E. W. Barankin and R. Dorfman; Research Report 42, June 1955; Management Sciences Research Project, University of California, Los Angeles 24, California.*

The problem is that of maximizing $g(x) = r(x) - s(x)$, where $r(x)$ is linear and $s(x)$ is positive semi-definite quadratic, over non-negative n-dimensional vectors x satisfying given linear inequality constraints. Conditions are obtained that $g(x)$ be bounded above subject to the constraints; and it is shown that if $g(x)$ is bounded above, then the constrained maximum is attained on a convex set, which reduces to a point when $s(x)$ is positive. The problem is transformed; and two algorithms for the transformed problem are proposed.

11. COSTS AND COSTS CONTROL. *(Accounting Concepts, Inspection, Budgets, Control Procedures, Purchasing.) (Note: There were no abstracts received from this solicitation.)*

12. INDUSTRIAL ENGINEERING EDUCATION. *(Industrial Engineering Education.)*

12. College Curriculum for a Bachelor's Degree in Industrial Engineering to Fill the Needs of Industry; *Floyd A. Turner; M.S. Thesis, May 1958, Southern Methodist University, Dallas 5, Texas.*

The thesis summarizes replies to questionnaires directed to approximately 100 selected industries regarding choice of subject matter to be incorporated into an undergraduate degree in Industrial Engineering. A composite curriculum is presented.

12. Development and Validity Testing of a Motion Study Visual Training Aid; *Jack I. Gronberg; M.S. Thesis, June 1948; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

A short training film on motion study was developed and its effects of the attitude of people viewing the film is measured and reported. The 424 Purdue juniors and seniors participating were administered one form of an attitude scale immediately prior to the showing of the film. A second form of the same scale was administered immediately following the showing. In all cases the results indicate an improvement in average group attitude toward motion study.

12. An Investigation of Text Material in Statistical Quality Control; *Rudolph Freedman; M.S. Thesis, June 1952; Engineering Library, Washington University, St. Louis 5, Missouri.*

An investigation of existing text material and development of a manual for instruction purposes in the field of statistical quality control. The manual provides a series of work sheets which bring out the practice through group exercise and demonstrations.

12. Organizational Planning for Naval Units *(NavPers 18371); 1955; Bureau of Naval Personnel, Personnel Research Division, Arlington Navy Annex, Washington 25, D.C.*

This manual is designed to acquaint officers and petty officers with the technique of organization planning and the part it plays in achieving and maintaining effective use of naval manpower. In addition, it furnishes guidance to command personnel in the conduct of organizational surveys and how best to utilize the results achieved.

12. Work Simplification for Naval Units, Briefing Manual *(NavPers 18358) October 1953; Bureau of Naval Personnel, Personnel Research Division, Arlington Navy Annex, Washington 25, D.C.*

This publication is designed to serve as a guide to conference leaders in indoctrinating officers and leading petty officers in the application of work simplification techniques for naval units. It outlines a step-by-step plan of instruction and describes the basic methods and materials needed for the establishment, coordination, and conduct of the work simplification program at the command level.

PLANNING AND CONTROLLING CAPITAL EXPENDITURES

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The Engineering Economy Division of ASEE and the Engineering Economy Research Committee of AIIE are co-sponsoring a two-day conference featuring industrial applications of engineering economy and related management techniques. The theme of this symposium is "Applications of Economic Evaluation in Industry." Topics covered include Capital Budgeting and Project Justification, Project Post Audit Analysis, Estimation of Working Capital Requirements, Effects of Taxes on Project Justification, and the Evaluation of Uncertainty. Speakers include leading experts in these fields from both industry and academic institutions.

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					Range in $1,000	Adv. degree req.?	Years of exper.	Age range	
								from	to
17	Air Force	O		11, 13, 42, 31, 38	8.8		4–5		
41	Consulting	O	×	10, 21, 31			5–7		
167	Weapons Systems	Wash DC		50	Ph.D.				
177	Education	NY		50+Gen. I.E.		M.S. or Ph.D.			45
199	Govt. Agency	Panama		Engr. Trainee	5.6–6.7			20	
213	Aircraft Repair & Mod.	Cal		15, 32, 42, 43, 44, 53	7.5		2½	21	
257	Chem. Proc.	Pa, WVa, Va		10, 21, 43	Open		1–5	Open	
273	Air Force	Utah		10 through 19	6.3–7.5		1½–2½		
274	Maint. Control	SC		11, 18, 52, 71, 90	7.5–8.2		2½		
275	Maint. Control	SC		11, 18, 52, 71	4.4–4.9		0		
279	Airline	Ill, Colo, Cal		11, 13, 42, 43, 70	5.0–8.0		2–8		
281	Education	Mo		10, 31		M.S. or Ph.D.			
299	Education	Mass		10, 20, 30, 40, 50					
301	M. Consulting	Upper Midwest	×	Broad	10.0–14.0		5–	28	50
302	Missile Production	Wash		10, 30, 40, 50, 70	6.0–11.5		1–		
303	Air Force Depot	NY		13, 31, 40, 91	4.4–7.5		0–3		
308	Automotive	Pa		19, 36, 38, 53	6.6–9.6		4–6		
311	Aircraft	Cal		11, 13, 15, 18, 33, 34, 35, 42, 43, 44, 47, 54, 71, 91, 92			5–		
313	Aircraft	O		42, 43, 44, 34, 18	5.4–7.2		1–	24	42
314	Mfg.-Steel PrMd.	O		36, 39, 48, 80, 97			5–10	25	35
315	Air Force	Cal		10, 13, 15, 32, 38, 42, 43, 44, 53	5.4–7.5	1 yr Spec. Field	2½	21	
316	Mining	Nev		10, 20, 30, 40	6.0–9.5			21	45
317	Mgmt. Consulting	NJ		10, 20, 31, 42, 54, 70	8.0–12.0		5	30	45
318	Wood & Plastics	Va		10, 11, 14, 15, 16, 18, 22, 21, 23	8.0–10.0		3–5	28	38
321	Steel	Ontario		10, 11, 21, 38, 91, 26					
322	Steel	Ontario		10, 11, 38					
323	Steel	Ontario		50, 54					
324	Steel	Ontario		10, 11, 21, 42					
325	Steel	Ontario		38, 53, 49					
326	Steel	Ontario		10, 13, 14, 15, 21					
327	Education	Fla							

Position number	Industry, location		Travel?	Job classification number (See key)	Salary	Qualifications required		
					Range in $1,000	Adv. degree req.?	Years of exper.	Age range
								from / to
328	Research & Edu.	Pa		26, 61, 64, 65				
329	Metal-Mach.	Mass		32, 36, 39	14.0–16.0			
330	Electro-Mech.	O		10, 16, 19	8.4–9.6		4–8	30
331	Plumbing Goods	WVa		10	4.2–4.8			
332	Printing	NY		11, 13, 18, 36, 37, 42, 43			5	35
333	Edu. (Wood Prod.)	NY		30, 37, 40				
334	Education	Fla		10, 26, 31–36, 40–45, 53, 66				
336	Steel	Mich		38	8.0–10.0		2–5	25 / 35
337	Research & Devel.	NJ		11, 13, 42	6.2		2–3	
338	Steel	Mich		10, 11, 19, 36	-6.0		25	35
339	Automotive	Pa		11, 13, 15, 16, 22, 23, 36	6.6–9.6		4–6	
340	Automotive	Pa		13, 14, 15, 16, 22	5.4–7.8		0–2	
341	Printing	NY		10, 11, 22, 32, 42, 43	7.8–9.5		3–5	
342	Com. Refrig.	NJ		10, 13, 14, 15, 20, 21, 22	8.0–11.0		8–10	30 / 40
343	Com. Refrig.	NJ		31, 32, 33, 34, 35, 94	8.0–10.0		10–12	30 / 40
344	Hosiery	NC		10, 11, 30	4.0–6.0		2–5	25 / 45
345	Govt. Agency	Wash., DC		10, 11, 42	8.2			
346	Education	Ga		19, 53, 51 (Research)	7.0–10.0	Degree M.S. or Ph.D.	2–5	30 / 45
347	Electronic Prod.	Ind		16, 19, 36, 39				
348	Administrative	(East)		10, 11, 13, 67, 71	14.0–16.0			
349	Plastic Prod.	Va		10, 21	8.0	MTM	25	38
350	Plastic Prod.	Va		91	10.0	Aircraft Exp.	30	45
352	Air Force	O		50	5.7–12.5			
353	Chemical Plant	La		10, 72, 13, 38, 63 (91 in Chem. Plant or Refinery)	8.4–10.0		5–10	30 / 40
354	Oil Field Equip.	Tex		10, 30, 39, 40	7.2–7.8	Mach. Shop Exp.	2–5	28 / 38
355	Non-Ferrous Metals	New Eng		92	12.0–17.0	I.E. Deg. Pref.	10–15	35 / 45
356	Chem. Proc. & Min.	Canada		92	12.0–14.0	I.E. Deg. Pref.	10	30 / 40
357	Chem. Proc. & Min.	Canada		91	8.0–10.0		5–10	25 / 30
358	Paper Mill	Pa		10, 13, 15, 21, 42	6.0–7.2		3–	
359	Mining	Peru		10, 11, 13, 18, 36, 38	Open		5–	
360	Electronics	Mass		10, 26, 32, 34, 36, 38, 39, 42, 49, 70, 91	5.0–9.0	Exp. in Electronics	3–5	
361	Mfg. & Fabr.	Tex		10, 18, 32, 40, 70, 92	8.5–10.0	Exp. in Welding	5–10	30 / 45
362	Aircraft	Conn		50, 51, 52	Open	Milit. & Ind. Exp.	1–4	
363	Oil Field Equip.	Tex		10, 19, 30, 32, 39, 40, 47, 70, 92	10.0–	Mach. Shop Exp.	7–10	30 / 45
364	Mfg.	Tex		10, 19, 30, 38, 39, 54, 91	8.5–10.0		5–10	30 / 40
365	Metal Fabr.	Tenn		10, 11, 21	6.0–7.2			25 / 40
366	Graphic Arts	Ind		11, 13, 36, 42, 43, 70	5.8–7.0		0–3	
367	Paper	Mo		10, 20, 42, 43, 70				
368	Metal Stamping	Conn		36, 39, 42, 44, 47	10.0–15.0		10–15	35 / 50
369	Metal Stamping	Conn		94	14.0–16.0		12–18	35 / 50
370	Air Force	O			8.8–10.0		4½	
371	Textile Prod.	SC		10, 20, 30, 40, 50				
372	Education	Ala			8.0 plus 2.0	Sor Summer Term—Ph.D. Pref.		
373	Education	Fla		37, 42, 50, 51, 53, 54				
374	Govt.	S.A., Asia, Africa		41, 49, 92, 93, 95, 96	10.0–16.0		10–	
375	Electronics	NY		30–39, 70–73	7.5–9.5		5–10	32 / 45
376	Education	Mass						35
377	Electronics	NY		10, 30, 40, 70	4.5–7.5			
378	Mgmt. Consulting	Ill	×	Broad	8.0–12.0		5–	28 / 40
379	Soft Goods Mfg.	Midwest		11, 13, 19, 31, 35, 43, 92, 93	12.0–		5–	45
380	Ind. Cons.	M.W. & S.W.		11, 13, 21, 31, 37, 42, 43	Open		5–	45
381	Steel	Ill		10, 20, 31–38	7.2–9.0	IBM Required	5–	27 / 35
382	Steel Proc. Warehouse	Mich		30, 40	Open		1–2	30
383	Govt. Agency	Africa, S.A., Near East, Far East		60, 70, 71	11.6–15.8	Management Exp.	10–	
384	Same as P-383			Broad	11.6–13.6			
385	Carpet Mfg.	South		10–19, 36	Open	I.E. Deg.	3–5	
386	Hospital	Ala		10, 30, 42, 53, 71, 72, 92	6.5–8.0	I.E. Deg. Reqd.	3–5	Open
387	Electronic	Tex		80, 81	7.2–8.4		3–5	
388	Electronic	Tex		36, 38	7.2–8.5	Accounting Deg.	2–5	
389	Electronic	Tex		10, 11, 13	7.0–8.4	I.E. Deg.		
390	Electronic	Tex		36, 38, 70	7.2–9.6	I.E. Deg.	2–5	25 / 40
391	Electronic	Tex		30, 31, 32, 33	7.0–9.0			25 / 35
392	Power Shovels	Wisc, Ind, Pa		10, 11, 13, 14, 15, 16, 21				

Key to Job Classifications

No.	Job Classification
10	Motion and Time Study
11	Methods Improvement
12	Suggestion Systems
13	Work Measurement and Perf. Stds.
14	Stop Watch Time Study
15	Std. Time Data Dev. & Applic
16	Predeter. Elemental Time Stds
18	Work Sampling
19	Estimating and Costing
20	Wage Payment
21	Incentive Plans
22	For Production Workers
23	For Non-Prod. Workers
24	For Supervisory Personnel
26	Job Evaluation
28	Wage Administration
30	Production Engineering
31	Production Control
32	Process Planning and Routing
33	Scheduling and Loading
34	Flow Process Charting
35	Inventory Control
36	Cost Anal. & Reduction
37	Statistical Quality Control
38	Budgetary Control, Standard Costs
39	Tool and Gage Design and Control
40	Plant Engineering
41	Plant Location & Expansion
42	Plant Layout
43	Material Handling
44	Machinery & Equipment
45	Specif., Select. & Eval.
46	Replacement
47	Automation
48	Plant Maintenance
49	Cap. Budget. Facil. Plan
50	Operations Research
51	System & Simulation with "Models"
52	Mathematical Analysis
53	Engr. Economy Studies
54	Auto. Data Proc. with Computers
55	Market Research & Forecasting
60	Industrial Relations
61	Personnel Administration
62	Personnel Testing
63	Personnel Training
64	Industrial Psychology
65	Labor Relations
66	Safety Engineering
67	Suggestion Systems
70	Systems and Procedures
71	Admin. & Operating Procedures
72	Organization Charts and Manuals
73	Records Admin. & Form Control
80	Product Design
81	Packaging
90	Management and Supervision
91	Industrial Engineering Supr.
92	Chief I. E. or Equiv.
93	Plant Engineer
94	Production Supervisor
95	Plant Mgr., Fact. Mgr., Works Mgr.
96	General Manager

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Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of men, materials and equipment; drawing upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems.